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Control of Waste and Water Pollution from Power Plant Flue Gas Cleaning Systems: First Annual R and D Report

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First Annual R and D Report

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16. ABSTRACT

The report summarizes and assesses the state of research and development in the fields of non-regenerable flue gas cleaning (FGC) waste treatment, utilization, and disposal, as well as water reuse technology, for coal-fired utility power plants. Significant results cover: (1) chemical and physical characterization of wastes from eastern and western U.S. plants using lime, limestone, or double-alkali scrubbing systems; (2) chemical and physical properties and leaching characteristics of treated and untreated wastes; (3) field evaluations of treated and untreated waste disposal; (4) disposal alternatives; (5) cost estimates for ponding and for fixation disposal methods; (6) disposal standards; (7) gypsum production and marketing; (8) potential use of wastes in fertilizer production and portland cement manufacture; (9) beneficiation studies; and (10) total power plant water reuse. Reports are to be issued annually to evaluate the progress of FGC waste disposal and utilization technology. Results, not available but to be included in subsequent reports, will cover: coal-pile drainage, ash characterization and disposal, soil attenuation effects, and conceptualized design cost analyses for various methods of FGC waste disposal.

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CONTROL OF WASTE AND WATER POLLUTION FROM POWER PLANT FLUE GAS CLEANING SYSTEMS: FIRST ANNUAL R AND D REPORT

by

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Office of Research and Development
Washington, DC 20460

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ABSTRACT

This initial report summarizes and assesses the state of research and development in the fields of nonregenerable flue gas cleaning waste treatment, utilization and disposal, as well as water reuse technology for coal-fired utility power plants. It is based upon information available through December 1975.

Significant results cover the following areas: chemical and physical characterization of wastes from eastern and western plants using lime, limestone, or double-alkali scrubbing systems; chemical and physical properties and leaching characteristics of treated and untreated wastes; field evaluations of treated and untreated waste disposal; disposal alternatives; cost estimates for ponding and for fixation disposal methods; disposal standards; gypsum production and marketing; potential use of wastes in fertilizer production and portland cement manufacture; beneficiation studies; and total power plant water reuse.

Future reports will be issued annually to evaluate the progress of flue gas cleaning waste disposal and utilization technology. Results not available, but to be included in subsequent reports, will cover the areas of coal-pile drainage, ash characterization and disposal, soil attenuation effects, and conceptualized design cost analyses for various methods of flue gas cleaning waste disposal.

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CONVERSION TABLE

A list of conversion factors for British units used in this report is as follows:

British	Metric
1 acre	4047 square meters
1 British thermal unit per pound	2.235 Joules per gram
1 foot	0.3048 meter
1 cubic foot per minute	28.316 liters
1 inch	2.54 centimeters
1 gallon	3.785 liters
1 pound	0.454 kilogram
1 mile	1.609 kilometers
1 ton (short)	0.9072 metric tons
1 ton per square foot	9765 kilograms per square meter
1 gram per square foot	10.76 grams per square meter
1 part per million	1 milligram per liter (equivalent)
1 pound per square inch	0.0703 kilogram per square centimeter
1 cubic yard	0.7641 cubic meter

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SECTION I

CONCLUSIONS

1.1 BACKGROUND

This report summarizes and assesses the state of research and development (R&D) in the fields of nonregenerable flue gas desulfurization (FGD) waste treatment, disposal, and utilization as well as water recycle and reuse for coal-fired utility power plants, with the ultimate objective being directed toward definition of cost-effective environmentally acceptable methods. A survey of the work being conducted indicates that a significant portion of effort is currently being conducted under the direction of the U.S. Environmental Protection Agency (EPA). Considerable efforts are also being conducted by others, including utilities and industrial organizations. Although most of these efforts are concerned with problems of a site-specific nature, they contribute to the over all understanding of the technical fields under study.

The EPA program consists of 19 projects that address the broad range of the flue gas cleaning (FGC) waste disposal and utilization spectrum. The projects, which are in various stages of accomplishment, encompass the areas of (1) technology and economic assessment of existing FGC waste treatment, disposal, and utilization processes; (2) development of new or evolving technology of treatment, utilization, and disposal; and (3) development of methods to improve power plant water reuse. Physical and chemical characterizations of untreated and treated FGD wastes from utility power plants burning eastern and western coals with a range of scrubber facility sizes, using lime, limestone, and double-alkali processes, are being conducted. A data base of criteria with which to assess environmental consequences of the identified disposal or utilization options is also being compiled.

Many of the EPA and industry studies are in an early stage; the EPA studies will require approximately one to two years to complete. Therefore, firm conclusions regarding results to date are not warranted at this time. However, some conclusions can be drawn relative to the EPA program scope and its potential to meet program objectives, and observations can be made on the basis of information currently available.

1.2 CONCLUSIONS AND OBSERVATIONS

Federal regulatory guidelines have not been promulgated which could be used to gauge the effects of FGD waste disposal on the quality of ground-water and on land reclamation. The results from this program will provide a data base for defining waste disposal standards and predicting effects on ground and surface water quality.

Specific observations made to date are as follows:

a. FGC waste chemical characteristics were found to be a function not only of the properties of coal and scrubber absorbent but also of the scrubber-operating parameters, primarily pH. The influence of operating variables on waste characteristics is being systematically studied as part of the program.

b. Physical and chemical properties of untreated and treated FGD wastes and liquors have been determined for lime, limestone, and double-alkali scrubber systems, using eastern and western coals. The resultant properties are process-and fuel-dependent. The data appear to be consistent in cases where analyses from different laboratories can be compared. Significant values are summarized in Section IV.

c. Interim results of tests of FGC wastes have shown that chemical treatment significantly improves the structural characteristics of the FGD waste, reduces the solubility of major chemical species by a factor of two to four and reduces permeability by an order of magnitude or more. No appreciable reduction of the concentration of trace elements in the leachate has been noted when compared to untreated wastes. Management of disposal sites to prevent collection of surface water would be a significent factor in minimizing or eliminating seepage through the waste.

d. With the increased acquisition of quantitative information anticipated during the program, a data base will be formed with which to determine the migration of major species and trace elements into FGD waste disposal sites and to assess the feasibility and environmental impact on alternative disposal sites such as landfills, ponds, mines, and oceans. This data base can be used by the EPA to define waste disposal guidelines.

e. The economics of FGD waste disposal and utilization will be defined in detail and will be available for assessment of the various disposal and utilization options. Engineering estimates of 30-year average total fixation and disposal costs (capital and operating) for a typical 1000-megawatt (MW) plant have been identified as $7.30 to $11.40 per ton of sludge (1975 dollars and dry weight basis). These estimates represent the range of costs for three different chemical treatment processes. The costs equate to $2.07 to $3.24 per ton of coal and 0.9 to 1.4 mils per kilowatt hour (kWh). Costs of disposing of untreated FGD wastes in lined ponds have been reported as approximately 75 percent of the fixation-disposal costs.

f. Work performed by utilities and chemical processors has ranged from laboratory research on processes and characterisitics of wastes to field evaluation of pilot plants and prototype treatment processes. The work has focused on site-specific problems of waste treatment and disposal faced by the utilities involved. The results, in general, complement and augment the EPA program.

g. At present, 8 stations have 13 units (5205 MW equivalent) committed to full-scale chemical treatment and disposal of FGD wastes through 1979. Of these, three units (767 MW) are in operation, and startup by three others (1413 MW) is planned by the end of 1976. The combined total for FGD waste disposal by ponding, projected or in use by 21 power plant units for 1976, is 4338 MW as contrasted to 2180 MW with chemical fixation of FGD wastes. Projections to 1983 identify approximately 68 units of approximately 26,400 MW committed to nonregenerable scrubbers, of which 15 units (7155 MW) are committed to chemical fixation.

SECTION II

RECOMMENDATIONS

2.1 BACKGROUND

A review and assessment was conducted of all known research and development (R & D) activities for flue gas cleaning (FGC) waste treatment, disposal, and water reuse to determine the completeness of the coverage regarding a total understanding of the problems and potential solutions. It was determined that current work, funded primarily by the U.S. Environmental Protection Agency (EPA), addresses a broad range of questions that must be answered prior to defining environmentally and economically sound flue gas desulfurization (FGD) waste disposal methods. The results from the EPA program, together with work being done by utilities and other organizations, form a significant data base to assist in achieving the stated objectives.

2.2 RECOMMENDATIONS

At present, no specific change in the direction of the EPA-sponsored program objectives is recommended. The various projects are complementary, and negligible duplication of effort was noted within the EPA program and between the EPA projects and work being conducted by others. For complete coverage of the problem, further considerations are given in the following recommendations.

a. In testing conducted as part of the EPA program, it has been determined that weathering deteriorates the physical properties of treated wastes. However, the data are limited, and follow-up work is recommended to define realistic test conditions and quantify the freeze-thaw wet-dry effects on the strength, permeability, and leaching characteristics of treated wastes.

b. Although the EPA program will result in the compilation of a data base encompassing the technology and properties of FGD wastes whereby disposal criteria can be defined and environmental impacts assessed, a series of detailed case studies are recommended where conditions at typical disposal sites in various regions of the United States may be evaluated. Based on the type of waste produced at each site, together with geological, climatalogical, and hydrological factors and site management techniques, an assessment of pollutant transport phenomena, environmental acceptability, and impact of various disposal methods can be made.

c. Plans were announced recently by the Electric Power Research Institute (EPRI) to sponsor projects for the development of a reliable design basis for lime and limestone scrubbing.[1] Recently, a memorandum of understanding was signed by EPA and EPRI calling for cooperation in research and development in areas of mutual interest.[45] Since the intent of the EPRI and EPA FGD waste treatment and disposal programs appears to be quite similar, it is recommended that a cooperate effort be pursued from which complementary objectives and goals can be derived and the duplication of effort minimized.

SECTION III

INTRODUCTION

3.1 BACKGROUND

A major consideration in the installation of flue gas cleaning (FGC) systems is the necessity for disposing of or utilizing the by-products. This applies to all coal-fired boilers, especially those with nonregenerable flue gas desulfurization (FGD) systems. Application of FGD systems in the United States is accelerating; the major portion of these are lime and limestone wet scrubbing systems, which produce a calcium sulfite waste. Environmental and economic concerns related to the disposition of this FGD waste are reflected in a broad range of research, development, and demonstration programs for its treatment and disposal.

A significant portion of the national effort is currently being funded by the Environmental Protection Agency (EPA). Nineteen different EPA projects are under way; the funding through fiscal year (FY) 1976 has been identified as $6.95 million, with an additional $4.7 million projected through FY 1980. Work has also been and is being conducted by utilities and other industrial organizations involved in the treatment and disposal process. In addition, full-scale systems are currently in operation, and others are in various stages of planning and implementation.

3.2 SCOPE

The Aerospace Corporation under Task 9 of EPA Contract No. 68-02-1010 has been contracted to integrate and evaluate the research and development (R & D) work being performed in the area of FGD waste treatment disposal and utilization, as well as overall power plant water recycle and reuse. This report is the first of an annual series that provides an evaluation of the R & D results of the EPA-funded projects, as well as those being conducted by other United States and foreign industrial organizations and by universities. The assessment of the results and technology is related to the definition of environmentally sound and economic disposal of or utilization of FGD wastes. In addition, a summary of the status of full-scale operational FGD waste disposal systems is reported.

3.2.1 The EPA Program

In late 1974, plans were formulated to greatly expand existing EPA FGD waste disposal R & D efforts. These efforts were aimed at determining pertinent environmental parameters, reducing costs, investigating alternative strategies, and encouraging waste-product usage. Although the major emphasis was on FGD wastes, the plans involved consideration of overall power plant waste and water problems, including the disposal and utilization of coal ash. For this reason, the new program was entitled "Control of Waste and Water Pollution from Flue Gas Cleaning (FGC) Systems" or, for brevity, the "FGC Waste and Water Program."

The objectives of the FGC Waste and Water Program are to evaluate, develop, demonstrate, and recommend environmentally acceptable cost-effective techniques for disposal and utilization of FGC wastes and to evaluate and demonstrate systems for maximizing power plant water recycling and reuse. The projects, in general, fall into one of six main categories: (1) environmental assessment of FGC waste disposal, (2) technology assessment development, (3) disposal economics, (4) alternative disposal methods, (5) utilization of wastes, and (6) overall power plant water use.

The environmental assessment projects include FGC waste characterization studies; laboratory and pilot field studies of disposal techniques for chemically treated FGD sludges; characterization of coal-pile drainage, coal ash, and other power plant effluents; and studies of attenuation of FGC waste leachate by soils. Chemical and physical properties have been determined by several laboratories for untreated FGC wastes from a total of 11 scrubbers and wastes treated by 5 distinct processes.

The technology assessment and development efforts include field studies of untreated and chemically treated FGC wastes; FGC waste leachate-disposal site liner compatibility studies; studies to correlate waste solid characteristics with scrubber operating conditions; and dewatering equipment design studies. The economic studies include cost estimates of current disposal practices (e.g., ponding, landfill) and by-product marketing studies. Alternative disposal method studies include both mine and ocean disposal assessments. Utilization projects include development of a process for FGC waste conversion (to sulfur and calcium carbonate); pilot studies of fertilizer production (using the waste as a filler material and a source of sulfur); use of FGD gypsum in portland cement manufacture; and FGC waste beneficiation studies. Although the work on power plant water use is a single study to maximize waste water reuse in the total power plant water system, the results from this project will be integrated with the studies of power plant effluents described earlier.

Table 1 shows the relationship of each of the projects to the areas of interest. Whereas four of the projects are aimed at investigating one specific area, the others cover several areas of interest. This is to be expected, since it would be difficult, for example, to fairly assess the technology of a process without examining both the economics and the environmental effects. An overview of the EPA program as it relates to the various elements of the FGC solid waste and liquid effluent generation, treatment, disposal, and utilization is shown in Figure 1. The projects and contractors are identified and keyed to the elements of the system addressed.

In Section V each of the projects is discussed, and the current project status and results are described. These are listed under the heading of the main area of interest. Table 2 identifies the EPA project officer, contractor project director, start date, and duration for each of the projects, as well as the section in which each of these projects is discussed.

Table 1. RELATIONSHIP OF PROJECTS IN FGC WASTE AND WATER PROGRAM TO AREAS OF INTEREST

Project	Contractor	Environmental Assessment	Technology Assessment and Development	Economic Studies	Alternative Disposal Methods	Utilization Methods Development	Overall Power Plant Water Use
FGC Waste Characterization and Disposal Evaluation	Aerospace[b]	X	X	X	X		
Shawnee FGD Waste Disposal Field Evaluation	TVA[c] and Aerospace[b]	X	X	X	X		
Laboratory and Field Evaluation of FGC Treatment Processes	U. S. Army WES[d]	X	X				
Characterization of Effluents from Coal-Fired Power Plants	TVA[e]	X					
Fly Ash Characterization and Disposal	TVA[e]	X	X	X			X
Attenuation of FGC Waste Leachate by Soils	U.S. Army, Dugway[f]	X					
Establishment of Data Base for FGC Disposal Standards	SCS[g]	X	X				
Evaluation of FGD Waste Disposal Options	LG&E[h]	X	X		X		
FGD Waste Leachate - Liner Compatibility	U.S. Army, WES[d]		X	X			
Scrubber Waste Characterization	TVA[e]		X				
Dewatering Principles and Equipment Design	Auburn U[i]		X				
Conceptual Design-Cost Studies of Alternative Methods for FGC Waste Disposal	TVA[j]		X	X			

(Continued)

Table 1. RELATIONSHIP OF PROJECTS IN FGC WASTE AND WATER PROGRAM TO AREAS OF INTEREST (Continued)

Project	Contractor	Environmental Assessment	Technology Assessment and Development	Economic Studies	Alternative Disposal Methods	Utilization Methods Development	Overall Power Plant Water Use
Gypsum By-Product Marketing Studies	TVA[j]		X	▨ X		X	
Evaluation of Alternative FGC Waste Disposal Sites	A. D. Little[k]	X	X	X	▨ X		
Scrubbing Waste Conversion Studies	Pullman Kellogg[l]		X	X		▨ X	
Fertilizer Production Using Scrubbing Wastes	TVA[j]		X	X		▨ X	
Use of FGD Gypsum in Portland Cement	SCPSA, Santee Cement, and B&W[m]		X	X		▨ X	
FGD Waste and Fly Ash Beneficiation	TRW[n]			X		▨ X	
Assess and Demonstrate Power Plant Water Reuse and Recycle	Radian[o]			X			▨ X

[a] Reference 2. Primary area of interest is indicated by shaded areas.

[b] The Aerospace Corporation, El Segundo, California.

[c] Tennessee Valley Authority (TVA), Division of Chemical Development, Muscle Shoals, Alabama.

[d] U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

[e] TVA, Power Research Staff, Chattanooga, Tennessee.

[f] U.S. Army Materiel Command, Dugway Proving Ground, Utah.

[g] SCS Engineers, Long Beach, California.

[h] Louisville Gas and Electric Company (LG&E), Louisville, Kentucky.

[i] Auburn University, Auburn, Alabama.

[j] TVA, Office of Agricultural and Chemical Development (OACD), Muscle Shoals, Alabama.

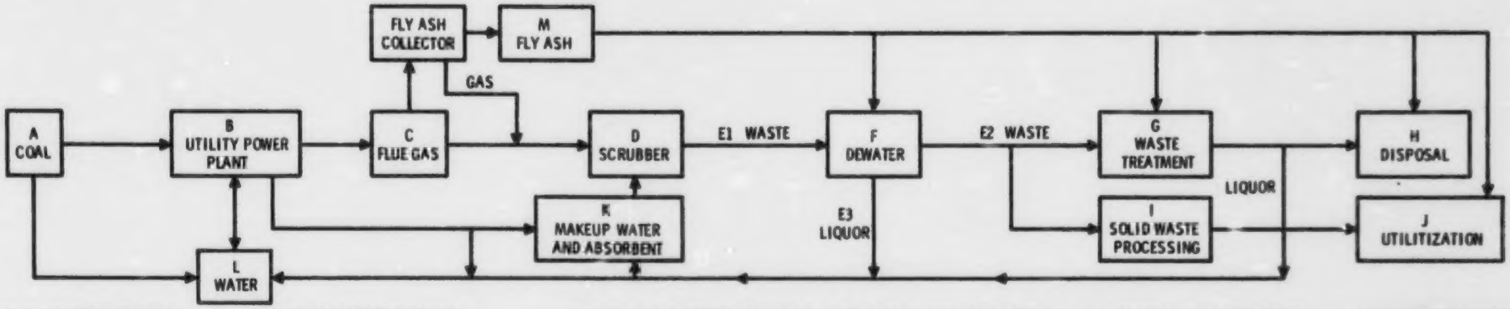
[k] Arthur D. Little, Inc., Cambridge, Massachusetts.

[l] Pullman Kellogg Company, Houston, Texas.

[m] South Carolina Public Service Authority (SCPSA); Moncks Corner, South Carolina; Santee Portland Cement Corporation, Holly Hill, South Carolina; and Babcock & Wilcox, Barberton, Ohio.

[n] TRW Systems Group, Redondo Beach, California.

[o] Radian, Inc., Austin, Texas.


FLY ASH COLLECTOR
M FLY ASH
GAS
A COAL
B UTILITY POWER PLANT
C FLUE GAS
D SCRUBBER
E1 WASTE
F DEWATER
E2 WASTE
G WASTE TREATMENT
H DISPOSAL
K MAKEUP WATER AND ABSORBENT
E3 LIQUOR
LIQUOR
I SOLID WASTE PROCESSING
J UTILITIZATION
L WATER

- CHARACTERIZATION OF EFFLUENTS FROM COAL-FIRED POWER PLANTS (TVA), A, C, L
- FLY ASH CHARACTERIZATION AND DISPOSAL (TVA) C, M, H
- ASSESS AND DEMONSTRATE POWER PLANT WATER REUSE/RECYCLE (Radian) L, B, K
- LIME AND LIMESTONE SCRUBBING WASTE CHARACTERIZATION (TVA) D, $E_{1,2,3}$
- FGC WASTE CHARACTERIZATION AND DISPOSAL EVALUATION (Aerospace) $E_{1,2,3}$G, H, K, L, M
- DEWATERING PRINCIPLES AND EQUIPMENT DESIGN STUDIES (Auburn U) F
- LABORATORY AND FIELD EVALUATION OF FGC TREATMENT PROCESSES (U. S. Army WES) G, E_2, H
- EVALUATION OF FGC WASTE DISPOSAL OPTIONS (LG&E) G, H
- CONCEPTUAL DESIGN AND COST STUDIES OF ALTERNATIVE METHODS FOR LIME AND LIMESTONE SCRUBBING WASTE DISPOSAL (TVA) G, H
- LIME AND LIMESTONE SCRUBBING WASTE CONVERSION PILOT STUDIES (Pullman-Kellogg)
- FERTILIZER PRODUCTION USING LIME AND LIMESTONE SCRUBBING WASTES (TVA) I, J
- USE OF FGD GYPSUM IN PORTLAND CEMENT MANUFACTURING (SCPSA), I, J
- SHAWNEE FGD WASTE DISPOSAL FIELD EVALUATION (TVA and Aerospace) H, G, E_2
- ATTENUATION OF FGC WASTE LEACHATE BY SOILS (U. S. Army, Dugway) H
- ESTABLISHMENT OF DATA BASE FOR FGC WASTE DISPOSAL STANDARDS DEVELOPMENT (SCS Engr) H
- ALTERNATIVE DISPOSAL METHODS DEVELOPMENT (A. D. Little) H
- FGC WASTE LEACHATE-LINER COMPATIBILITY (U. S. Army WES) H
- FGD WASTE AND FLYASH BENEFICIATION STUDIES (TRW) J, I
- GYPSUM BY-PRODUCT MARKETING STUDIES (TVA) J

Figure 1. EPA program overview: control of waste and water pollution from FGC systems

Table 2. PROJECT STATUS

Project Title	EPA Project Officer	Contractor Project Director	Start Date	Duration, Months	Type of Study	Section Referenced in This Report
Environmental Assessment of FGC Waste Disposal						5.1
FGC Waste Characterization, Disposal Evaluation, and Technology Transfer	J. W. Jones Industrial Environmental Research Laboratory (IERL) Research Triangle Park, NC	J. Rossoff The Aerospace Corporation El Segundo, CA	Nov 1972	50	Laboratory analyses: technical and economic	5.1.1
Shawnee FGD Waste Disposal Field Evaluation	J. W. Jones IERL Research Triangle Park, NC	J. Schults TVA, Division of Chemical Development Muscle Shoals, AL J. Rossoff The Aerospace Corporation El Segundo, CA	Sep 1974	34	Field evaluation	5.1.2
Laboratory and Field Evaluation of FGC Waste Treatment Processes	R. E. Landreth Municipal Environmental Research Laboratory (MERL) Cincinnatti, OH	J. L. Mahloch U.S. Army Engineer Waterways Experiment Station (WES) Vicksburg, MS				5.1.3
a. Pollution Potential of Untreated and Chemically Fixed Sludges			a. Jul 1974	a. 36	a. Laboratory	5.1.3.1
b. Site Survey and Environmental Assessment of Existing Solid Waste Disposal Sites			b. Jul 1975	b. 24	b. Laboratory, field	5.1.3.2
c. Evaluation of Existing Fixation Technology			c. Jul 1975	c. 26	c. Laboratory	5.1.3.3
Characterization of Effluents from Coal-Fired Power Plants	J. W. Jones R. A. Venezia IERL Research Triangle Park, NC	B. G. McKinney H. B. Flora TVA Power Research Staff Chattanooga, TN	Apr 1975	50	Laboratory, field	5.1.4
Fly Ash Characterization and Disposal	J. W. Jones R. A. Venezia IERL Research Triangle Park, NC	S. S. Ray TVA, Power Research Staff Chattanooga, TN	Apr 1975	42	Laboratory, field	5.1.5
Studies of Attenuation of FGC Waste Leachate by Soils	M. Roulier MERL Cincinnatti, OH	M. Houle U.S. Army Materiel Command Dugway Proving Ground Dugway, UT	Dec 1975	24	Laboratory	5.1.6

(Continued)

Table 2. PROJECT STATUS (Continued)

Project Title	EPA Project Officer	Contractor Project Director	Start Date	Duration, Months	Type of Study	Section
Establishment of a Data Base for FGC Waste Disposal Standards Development	D. E. Sanning MERL Cincinnatti, OH	G. J. Schmidt SCS Engineers Long Beach, CA	Dec 1975	15	Technical analysis	5.1.7
Process Technology Assessment and New Technology Development						5.2
Evaluation of FGD Waste Disposal Options	J. W. Jones IERL Research Triangle Park, NC	R. P. Van Ness Louisville Gas and Electric Co. Louisville, KY	Being negotiated	18	Laboratory, field	5.2.1
FGD Waste Leachate-Liner Compatibility	R. E. Landreth MERL Cincinnatti, OH	Z. B. Fry U.S. Army WES Vicksburg, MS	Jul 1975	30	Laboratory	5.2.2
Lime and Limestone Wet Scrubbing Waste Characterization	J. W. Jones IERL Research Triangle Park, NC	J. L. Crowe TVA Power Research Staff Chattanooga, TN	May 1975	28	Laboratory, field	5.2.3
Dewatering Principles and Equipment Design Studies	J. W. Jones IERL Research Triangle Park, NC	J. C. Warman Auburn University Auburn, AL	Being negotiated	27	Laboratory	5.2.4
Process Economics Studies						5.3
Conceptual Design and Cost Studies of Alternative Methods for Lime and Limestone Scrubbing Waste Disposal	R. D. Stern IERL Research Triangle Park, NC	H. L. Faucett TVA, Office of Agricultural and Chemical Development (OACD) Muscle Shoals, AL	Jan 1976	18	Technical and economic analyses	5.3.1
Gypsum By-Product Marketing Studies	C. J. Chatlynne IERL Research Triangle Park, NC	J. I. Bucy TVA, OACD Muscle Shoals, AL	Jan 1976	12	Technical and economic an analyses	5.3.2
Alternative FGC Waste Disposal Methods						5.4
Evaluation of Alternative FGD Waste Disposal Sites	J. W. Jones IERL Research Triangle Park, NC	R. R. Lunt Arthur D. Little, Inc. Cambridge, MA	Jul 1975	8	Technical analysis	5.4.1

(Continued)

Table 2. PROJECT STATUS (Continued)

Project Title	EPA Project Officer	Contractor Project Director	Start Date	Duration, Months	Type of Study	Section
New FGC Waste Utilization Methods						5.5
Lime and Limestone Scrubbing Waste Conversion Pilot Studies	J. W. Jones IERL Research Triangle Park, NC	A. G. Sliger Pullman Kellogg Company Houston, TX	Being negotiated	11	Bench, pilot plant	5.5.1
Fertilizer Production Using Lime and Limestone Scrubbing Wastes	J. W. Jones IERL Research Triangle Park, NC	J. L. Crowe TVA, Power Research Staff Chattanooga, TN	May 1975	41 (plus 18 for field tests)	Pilot plant, field tests	5.5.2
Use of FGD Gypsum in Portland Cement Manufacturing	J. W. Jones IERL Research Triangle Park, NC	M. O. McMinch SCPSA Moncks Corner, SC	Being Negotiated		Laboratory, pilot plant, full-scale process evaluation	5.5.3
FGD Waste and Fly Ash Beneficiation Studies	J. W. Jones IERL Research Triangle Park, NC	J. Blumenthal TRW Systems Group Redondo Beach, CA	Mar 1976	6	Conceptual design, bench, pilot plant	5.5.4
Improving Overall Power Plant Water Use						5.6
Assess and Demonstrate Power Plant Water Reuse and Recycle	F. A. Roberts IERL Research Triangle Park, NC	D. M. Ottmers Radian, Inc. Austin, TX	July 1975	13	Analysis of field data, computer simulation	5.6.1

3.2.2 Other Programs

Other organizations including utilities and FGD waste fixation contractors have conducted work on various aspects of the overall disposal problem that are generally of a site-specific nature. The results of work conducted by United States industrial organizations are discussed in Section VII, and the status of full-scale operational FGD waste disposal system is provided in this section. Section VI provides information on university-related work, and foreign technology is discussed in Section VIII.

3.3 TECHNICAL BASIS FOR THIS REPORT

This initial report is based generally on published information available through December 1975. During its preparation, a significant amount of information not available previously was presented at the 1976 EPA symposium on FGD[3] in New Orleans and is included. Annual updating of this report is planned by the EPA.

SECTION IV

SUMMARY

This initial report summarizes and evaluates the research and development (R&D) work being done in the field of coal-fired utility power plant flue gas cleaning (FGC) waste treatment, disposal, and utilization and overall power plant water recycle and reuse. The results of the various projects being funded by the U.S. Environmental Protection Agency (EPA) and private industry are viewed with the ultimate objective of recommending environmentally acceptable cost-effective waste disposal and utilization methods.

4.1 APPROACH

Nineteen EPA projects encompass the areas of (1) technology and economic assessment of existing FGC waste treatment, disposal, and utilization processes; (2) development of new or evolving technology of treatment, utilization, and disposal; and (3) development of methods to improve overall power plant water use.

Some of the EPA projects are just being initiated while others have been under way for several years. The projects that address the physical and chemical characterization of the FGC wastes have been funded for the longest periods. Therefore, considerable information required in the evaluation process in these areas is available and is summarized. This report includes data available through December 1975; other significant information published during preparation of this report is also included.

A diagram defining the approach being taken in the evaluation of the work being conducted in the EPA program is given in Figure 2. Industrial organizations have conducted privately funded work, primarily on problems of a site-specific nature. The work performed by these organizations (described in Sections VI and VII) will serve to supplement the EPA program results and will also be reported by EPA as the results are made public.

4.2 FINDINGS

A summary of the findings is presented in the following areas:

a. Effect of process variables on waste characteristics

b. Physical and chemical characterization of wastes

c. Disposal economics

d. Environmental assessment

e. Disposal alternatives

The status of operational flue gas desulfurization (FGD) disposal is also included.

Significant data exist for items a, b, and c. Some insights into the environmental assessment and the various disposal alternatives (items d and e) are available, but results and recommendations in these areas depend to a great extent on the outcome of future work. Firm conclusions and recommendations in all areas will emerge as more information becomes available over the next one to two years.

4.3 EFFECT OF PROCESS VARIABLES

A number of variables affects the chemistry of the various process streams and results in different chemical characteristics and properties of the materials to be disposed.

The results are based on chemical analyses of samples from seven different scrubbers having capacities ranging from 1 to 125 MW equivalent. They are reported as a function of location within a scrubber circuit as well as a function of time, pH, absorbent, and coal composition.[5]

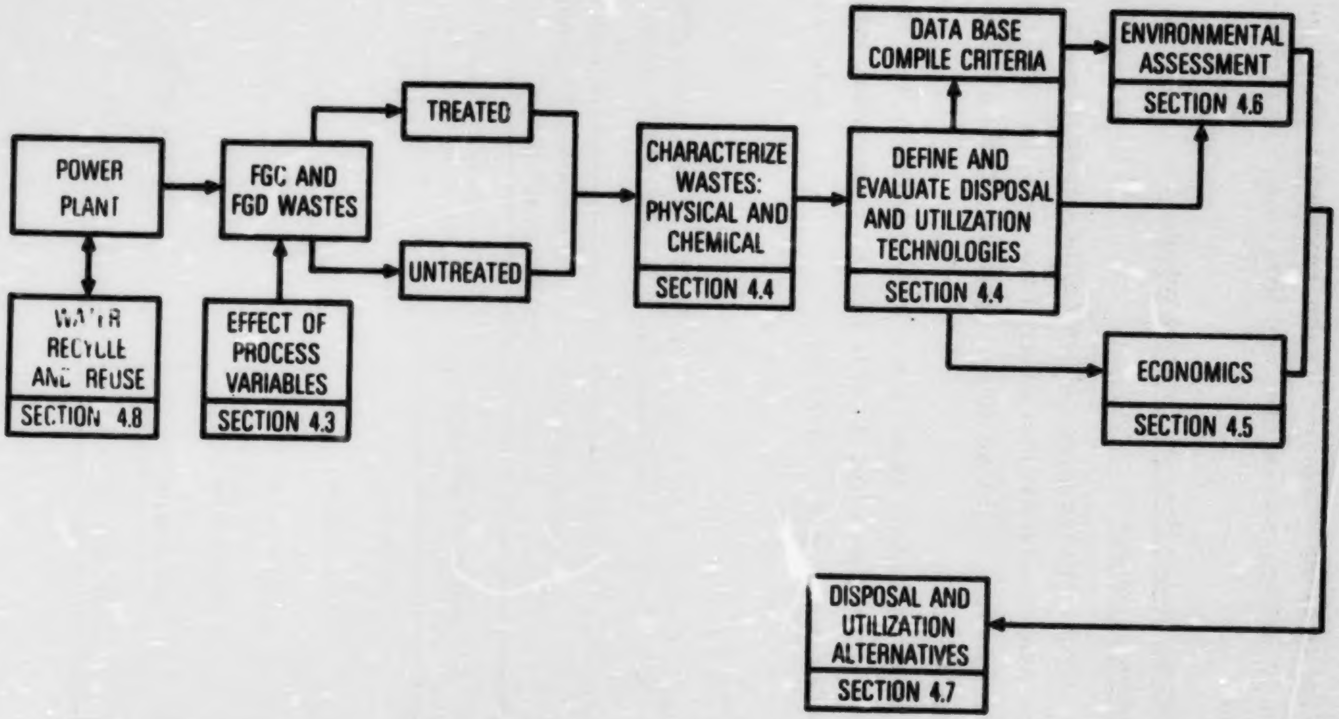

POWER PLANT
WATER RECYCLE AND REUSE
SECTION 4.8
FGC AND FGD WASTES
EFFECT OF PROCESS VARIABLES
SECTION 4.3
TREATED
UNTREATED
CHARACTERIZE WASTES: PHYSICAL AND CHEMICAL
SECTION 4.4
DATA BASE COMPILE CRITERIA
DEFINE AND EVALUATE DISPOSAL AND UTILIZATION TECHNOLOGIES
SECTION 4.4
ENVIRONMENTAL ASSESSMENT
SECTION 4.6
ECONOMICS
SECTION 4.5
DISPOSAL AND UTILIZATION ALTERNATIVES
SECTION 4.7

Figure 2. EPA program evaluation approach

A systematic and detailed evaluation of process variable effects on the scrubber solids is being attempted by the Tennessee Valley Authority (TVA) using the two 10-MW prototype lime and limestone scrubbing systems at the Shawnee plant.

4.3.1 Effect on Major Species Concentration in Scrubber Liquors

The effect of process variables on the concentration of chemical constituents was determined as a function of the location within a scrubber circuit, as well as a function of the scrubber process itself, i.e., lime, limestone, and double-alkalis.

The various constituents are affected differently. The end-to-end changes for the various constituents relating the constituent concentrations of the solid waste supernate to those in the scrubber liquors are shown in Table 3.

Table 3. RELATIVE CHANGE IN CONCENTRATION OF CONSTITUENTS IN THE SCRUBBER CIRCUIT: LIMESTONE PROCESS

Constituent	Typical Change in Concentration Between Scrubber and Disposal Stage[a]	
	Direction of Change	Change Between Scrubber Stage and Disposal Stream
Calcium	Decrease	30 to 40%
Chloride	Decrease	20%
Sulfite	Decrease	>99%
Sulfate	Decrease	10%
Trace Metals	Decrease	10 to 20%
pH	Increase	2 units

[a] Reference 37

4.3.2 Effect of Time on Scrubber Liquor Trace Element Concentration

The effect of time on trace element concentration from scrubber startup was reported[5] and is summarized as follows:

a. Trace element concentrations reached steady-state levels after building up during an initial scrubber startup period

b. For lead, there was a direct relationship between concentration and time.

4.3.3 Effect of pH on Scrubber Liquor Trace Element Concentration

Within an individual process, no correlation was detected between trace element concentration and scrubber liquor pH, except for lead, which generally increased with increasing pH.[5]

4.3.4 Effect of Absorbent on Scrubber Liquor Trace Element Concentration

The relative concentration of trace elements in scrubber liquors from the limestone, lime, and double-alkali processes has been determined.[5] Generally, trace element concentrations were highest in the limestone system, intermediate in the lime, and lowest in the double-alkali process; however, the actual concentration differences attributable to the process are not considered significant relative to their pollutional potential. The data indicate that the concentration effect is a consequence of pH within the respective scrubbers and as such is not a pollution control mechanism.

4.3.5 Effect of Coal Composition on Solid Waste and Liquor Trace Element Concentration

The concentration of trace metals in treated solids was reported as exhibiting a linear relationship with the concentration in the coal.[5] The trace metal concentration measured in the sludge liquor was two orders of magnitude lower than that measured in the solids.

The major source of trace metals in the solid waste is the coal. Also, the concentration of various trace elements in sludge parallels the differing concentrations typically found in eastern and western coals.

4.4 PHYSICAL AND CHEMICAL CHARACTERISTICS OF WASTES

4.4.1 Physical Properties

Properties that define handling and engineering characteristics of untreated and treated sludges have been reported.[4,5,12,14] These include viscosity, bulk density, and dewatering characteristics; porosity; permeability; and unconfined compressive strength.

Viscosity is a major factor in determining pumping power requirements. Bulk density data are needed in defining the volume of waste and disposal site acreage, and dewatering characteristics are important in defining treatment or conditioning requirements as well as achieving the potential of specific bulk densities. Compressive strength provides a measure of structural quality. Porosity and permeability determine rate of leachate penetration through the solid waste mass. Hence, the rate and quantity of leachate constituents entering the ground, i.e., mass loading, can be defined.

4.4.1.1 Viscosity

The viscosity of FGD wastes from seven power plants is presented as a function of solids content in Figure 3. The results show that of the wastes tested, pumpable mixtures (<20 poise) range from a high solids content of 70 percent for the Cholla limestone sample to a low solids content of 32 percent for both the Utah and GM double-alkali samples. Considering this wide range of solids content, the importance of experimentally determining the viscosity becomes evident.

Test results suggest that fly ash in FGD wastes decreases the viscosity of FGD wastes. Particle shape, size, and distribution may influence viscosity, but the extent is indeterminant at present.

CURVE	SOURCE	DATE	FLY ASH, %
①	ARIZONA CHOLLA LIMESTONE	4/1/74	58.7
②	SCE MOHAVE LIMESTONE	3/30/73	3.0
③	TVA SHAWNEE LIMESTONE	7/11/73	40.9
④	TVA SHAWNEE LIMESTONE	6/15/74	40.1
⑤	TVA SHAWNEE LIMESTONE	2/1/73	20.1
⑥	DUQUESNE PHILLIPS LIME	6/17/74	59.7
⑦	TVA SHAWNEE LIME	3/19/74	40.5
⑧	UTAH GADSBY DOUBLE ALKALI	8/9/74	8.6
⑨	GM PARMA DOUBLE ALKALI	7/18/74	7.4

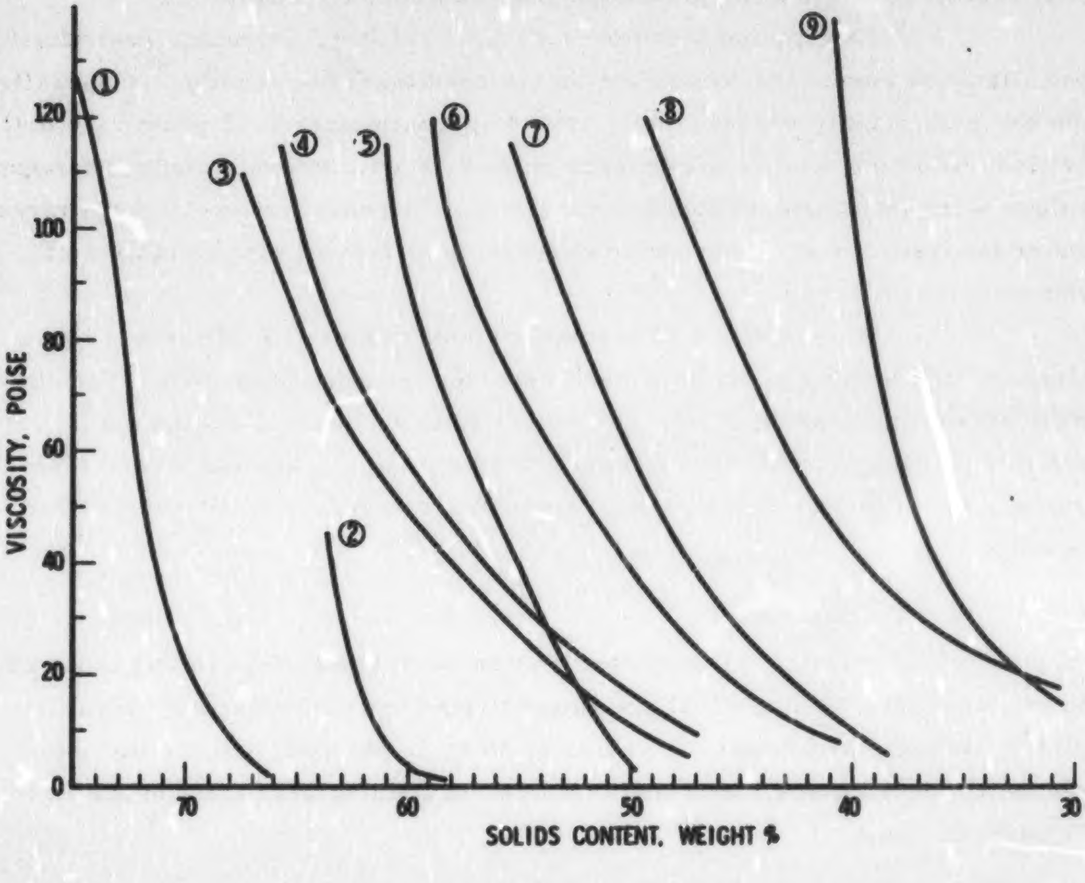


Figure 3. Viscosity of FGD wastes

4.4.1.2 Bulk Density

The dry bulk density of untreated FGC wastes is reported[12] to be in the range of 0.75 to 1.01 g/cm^3 (47 to 63 pcf), the actual value being scrubbing-process and coal-source dependent.

For the wastes examined, chemical treatment increases the dry bulk density to approximately 0.80 to 1.12 g/m^3 (50 to 70 pcf) for wastes with 0.75 g/cm^3 untreated density, and 1.28 to 1.76 g/cm^3 (80 to 110 pcf) for those characterized by the higher 1.01 g/cm^3 untreated densities. Again, coal source and scrubbing process appear to affect the values.

Dewatering techniques such as settling, draining, centrifuging, and filtration have a marked effect on the resultant bulk density.[5] Generally, the wet bulk density varied from a low of approximately 1.52 g/cm^3 (95 pcf), settled, to a high of 1.76 g/cm^3 (110 pcf), filtered. Drained and centrifuged values were intermediate to these extremes. These values were determined under laboratory conditions and may not necessarily be representative of commercial processes.

Some settling characteristics of wastes from lime and limestone scrubbing processes have been reported informally by TVA. For the wastes examined, settling rate curves for lime wastes are continuous, whereas settling curves for limestone wastes exhibit a discontinuity resulting in a sharp increase in settling rate prior to reaching maximum settled density.

4.4.1.3 Porosity

Porosity of untreated wastes were found to be in the range of 48 to 75 percent.[12] Chemical treatment tended to reduce porosity significantly, in some processes, to values of 35 to 55 percent, while other processes produced a solid with little change, remaining primarily in the 70 to 75 percent range.

4.4.1.4 Permeability

The permeability coefficients of untreated wastes were reported to be in the range of 10^{-4} to 10^{-5} cm/sec.[5,12] These values are intermediate to typical values for silty sand and sandy clay, which are 10^{-4} cm/sec and 5×10^{-6} cm/sec, respectively. Chemical treatment tended to reduce permeability by less than a factor of two in some cases, and several orders of magnitude in others. The chemical treatment process used appears to be the major determinant in the magnitude of the reduction.

Weathering such as freezing and thawing has been reported to break up the monolithic structure of certain treated wastes.[12] The permeability of several treated wastes that were mechanically fractured and powdered to simulate extensive weathering exhibited permeability values approximately the same as for untreated wastes. Fracturing (but not powdering) and compacting resulted in about one order of magnitude reduction of permeability relative to the powdered condition.[5]

4.4.1.5 Compressive Strength

Unconfined compressive strength of untreated wastes is low. No specific values are reported since the material is considered nonstructural. Chemically treated sludges exhibited unconfined compressive strengths ranging from approximately 25 psi to as high as 4500 psi in laboratory studies.[5,12,27] However, commercial processes being used at power stations today produce values in the range of 25 to 400 psi. Materials with unconfined compressive strengths of 25 psi are considered capable of supporting heavy-equipment traffic.[5]

A relationship between permeability and unconfined compressive strength of treated wastes may exist, i.e., the lower the compressive strength, the higher the permeability.[27] However, the correlation has not been established using a broad range of wastes.

4.4.2 Chemical Properties

Chemical properties of scrubber waste liquors and solids and FGC waste leachates have been reported.[5,12] More data are becoming available on FGC waste leaching characteristics as the program progresses and are being used to define long-term trends.

Chemical, x-ray, and scanning electron microscope analyses of the solid fractions of the wastes have shown the uniqueness of the characteristics, with properties affected by coal composition and scrubber operating variables.[5]

4.4.2.1 Quality of Scrubber Liquors

The range of concentrations of scrubber liquor constituents from five utility power plants is shown in Table 4. On the basis of the constituent levels in the liquor stream and the probability that the scrubber represents the end-of-the-line in the overall utilization of recycled power plant water, any purged water would require treatment prior to disposal.

4.4.2.2 Leaching Characteristics

4.4.2.2.1 Untreated Wastes

From an overall assessment of leaching data, it was concluded that for the major species, i.e., sulfate and chloride ions, and total dissolved solids (TDS), concentration in the leachate decreases rapidly during the first three pore volume displacements (PVD) where about 90 percent of the decrease takes place relative to the fifth pore volume.[5] The concentrations at the 50th pore volume are approximately the same as at the 5th.

For untreated wastes, the pH of the leaching solution showed no discernible effect on the leachate except for the trace elements lead and zinc, which were leached more readily by acidic conditions.

Untreated wastes have been leached under both aerobic and anaerobic leaching conditions. The anaerobic conditions simulated the effect of wastes with a high affinity for oxygen as is the case for sulfite sludges or

Table 4. RANGE OF CONCENTRATION OF CONSTITUENTS IN SCRUBBER LIQUORS[6]

Constituent	Range of Concentration at Potential Discharge Point, mg/ℓ		
Aluminum (Al)	0.03	to	0.3
Antimony (Sb)	0.09	to	2.3
Arsenic (As)	< 0.004	to	0.3
Beryllium (Be)	< 0.002	to	0.14
Boron (B)	8.0	to	46.
Cadmium (Cd)	0.004	to	0.11
Calcium (Ca)	520.	to	3000.
Chromium (Cr)	0.01	to	0.5
Cobalt (Co)	0.10	to	0.7
Copper (Cu)	< 0.002	to	0.2
Iron (Fe)	0.02	to	8.1
Lead (Pb)	0.01	to	0.4
Magnesium (Mg)	3.0	to	2750.
Manganese (Mn)	0.09	to	2.5
Mercury (Hg)	0.0004	to	0.07
Molybdenum (Mo)	0.91	to	6.3
Nickel (Ni)	0.05	to	1.5
Potassium (K)	5.9	to	32.
Selenium (Se)	< 0.001	to	2.2
Silicon (Si)	0.2	to	3.3
Silver (Ag)	0.005	to	0.6
Sodium (Na)	14.0	to	2400.
Tin (Sn)	3.1	to	3.5
Vanadium (V)	< 0.001	to	0.67
Zinc (Zn)	0.01	to	0.35
Carbonate (CO_3)	< 1.0	to	< 10.
Chloride (Cl)	420.	to	4800.
Fluoride (F)	0.07	to	10.
Sulfite (SO_3)	0.8	to	3500.
Sulfate (SO_4)	720.	to	10,000.
Phosphate (PO_4)	0.03	to	0.41
Nitrogen (N) (total)	< 0.001	to	0.002
Chemical Oxygen Demand	60.	to	390.
TDS	3200.	to	15,000.
Total Alkalinity (as $CaCO_3$)	41.	to	150.
Conductance, mho/cm	0.003	to	0.015
Turbidity, Jackson units	< 3.	to	< 10.
pH	3.04	to	10.7

conditions in the lower layers of wastes in a covered landfill. The results showed that, at any given displacement volume, a greater drop in concentrations of major species in the leachate occurs with anaerobic conditions than with aerobic conditions. At the fifth pore volume for aerobic conditions, the sulfate concentrations reached 1100 to 1300 mg/l and chloride 95 to 130 mg/l, irrespective of the initial concentration in the mother liquor. The corresponding concentrations for the anaerobic conditions are 900 to 1100 mg/l and 65 to 70 mg/l for sulfate and chloride ion concentrations, respectively. No relationship of this nature has been found for trace metals.

4.4.2.2.2 Treated Wastes

As with untreated wastes, the reduction of major species concentrations generally takes place within the first three pore volumes.[5]

On the basis of laboratory and field test results, it was reported that the concentration of the TDS in the first pore volume of the treated leachate is approximately 50 percent of the untreated sludge leachate.[5] After the initial flushing period of 3 to 5 pore volumes, the concentrations generally remained constant thereafter with values from the treated wastes being approximately 25 to 50 percent of those from the untreated wastes.

On the basis of somewhat limited leaching tests evaluating five chemical treatment processes, another laboratory has reported mixed results relative to improvement in the leachate quality from treated wastes.[12] However, further testing is being conducted, as planned, to verify initial trends and to permit an assessment of the performance of each of the five individual chemical processes.

The effect of chemical treatment on immobilizing trace elements is not discernable at present when compared to untreated materials because of low concentrations and significant scatter in much of the data.[5] With additional leaching data, statistical techniques may be useful to determine the effect of chemical treatment. Also, there is some evidence to suggest that in certain instances the additives used in the chemical treatment of FGD wastes may be contributing trace metals to the leachate.[5]

4.5 DISPOSAL ECONOMICS

4.5.1 Chemical Treatment and Disposal

Engineering estimate costs for disposal of chemically treated FGC wastes from a 1000-MW plant burning eastern coal were reported:[13]

Total Disposal Costs, 1975 Dollars, 30-Year Average

Sludge, Including Fly Ash, per Ton (Dry Basis)	Coal per Ton (Eastern)	Mills per kWh
$7.30 to 11.40	$2.07 to 3.24	0.9 to 1.4

These costs represent the range of estimates for three fixation-disposal processes. The average annual operating load factor was assumed to be 50 percent over a 30-year lifetime, with the disposal site 5 miles away from the power plant. Locating the disposal site 0.5 mile from the power plant rather than 5 miles and increasing the annual average operating load factor from 50 to 65 percent reduces the disposal costs by approximately 9 and 7 percent, respectively. More detailed cost analyses of several disposal processes will be conducted by TVA, and results from this study will be reported as they become available.

4.5.2 Ponding

Disposal pond costs are dependent on construction and material factors as well as land costs. For PVC-20 and Hypalon-30 materials, which represent a reasonable range of liner material costs, the disposal costs on a dry weight basis for a 1000-MW plant are $5.70 to 7.80 per ton of sludge, or approximately 75 percent of those for chemical treatment and disposal.[5]

4.6 ENVIRONMENTAL ASSESSMENT

Data from the various projects are not sufficient for an overall environmental assessment of the effects of disposal on water quality and land reclamation. It has been determined that untreated waste chemical properties tend to be a function of the coal and scrubbing process variables. Furthermore, chemically treated waste characteristics are also a function of the treatment process itself. Prime factors to be considered in the disposal of FGD wastes are as follows.

4.6.1 Strength

Because of the thixotropic nature and structural characteristics of untreated wastes, personnel and equipment safety cannot be assured. Treated material, depending on the fixation process and the solids content, can be expected to achieve strengths in excess of those considered minimal for supporting personnel and equipment and, in some cases, building structures. The long-range effect of weathering, i.e., wet-dry and freeze-thaw cycling, is yet to be defined.

4.6.2 Permeability

Permeability of untreated material is approximately 10^{-4} to 10^{-5} cm/sec. Chemical treatment tends to reduce these values over a broad range, from negligible to several orders of magnitude depending on the process selected. The long-range effect or weathering on permeability is yet to be determined.

4.6.3 Leachate Concentration

Laboratory and field leaching data have shown that leachate concentrations of major species in the leachate from fixed materials are about 25 to 50 percent of the concentrations of major species in untreated materials.

4.6.4 Leachate Mass Release

The mass release of major constituents into the soil from chemically fixed materials is reduced as a result of lower permeability of the treated wastes, as well as a reduction of the solubility of major pollutant constituents. Treatment process and mode of disposal, i.e., pond, landfill, or lake, determine the mass loading of pollutants into the soil, which can amount to reduction of one to two orders of magnitude when compared to untreated materials.

4.7 DISPOSAL AND UTILIZATION ALTERNATIVES

Disposal alternatives being studied include assessment of the environmental effects of disposal of treated and untreated wastes in mines and oceans, as well in landfills and ponds. A data base is also being established for the development of FGC waste divisional standards. Results from these projects, as well as others described later in this section will be reported as they become available.

Studies will also be conducted to determine dewatering characteristics of FGC wastes in order to define areas where improvements can be made in dewatering equipment or techniques. Results from this work will be used in assessing potential benefits resulting from reduction of equipment size, waste volume handled, disposal acerage, and chemical additives.

Utilization of FGC wastes can be considered as an alternative to disposal. In this regard, the use of FGD wastes in the manufacture of fertilizer is being studied by TVA and at the Illinois Institute of Technology.[21] Experiments on forced oxidation of sulfite sludges to form gypsum for potential use in wallboard are being conducted, and the economics of the process and a survey of potential markets are also being initiated. A project to use FGD gypsum in cement manufacturing is expected to get under way shortly, as is the evaluation of a process that uses FGD waste to produce elemental sulfur. A conceptual design and cost study on beneficiation or alumina and dicalcium silicate from FGC wastes is also being initiated.

The environmental effects of an alternative treatment and disposal method wherein sulfite FGC wastes are oxidized to gypsum are in the early stages of experimental assessment.

4.8 POWER PLANT WATER RECYCLE AND REUSE

Chemical characterization of water streams from three plants is being conducted and computer-assisted simulation of existing plant water utilization operations will be made. Technical assessments will then be performed of water recycle and reuse options formulated to minimize water requirements and discharges. Cost estimates of each viable option will be prepared. Pilot plant testing of one or more of the options will follow.

4.9 FULL-SCALE APPLICATIONS

Six utilities, with 13 power stations (5205 MW equivalent) have been currently identified as committed to disposal of chemically treated FGC wastes. Three power stations (767 MW) are in operation; startup by three others (1413 MW) is planned by the end of 1976; and the remaining will begin FGC treatment and disposal by 1979. The total quantity of untreated FGC wastes being ponded in 1976 is 4338 MW equivalent.

In Japan, large-scale utilization in the wallboard and cement industries of gypsum produced from FGD wastes is in progress. As discussed previously, experimental work and economic studies are being initiated in the United States. A lime-based process that forms gypsum was announced recently by Holter in West Germany.[44]

SECTION V

EPA-SPONSORED RESEARCH AND DEVELOPMENT

The U.S. Environmental Protection Agency (EPA) Program for Control of Waste and Water Pollution from Flue Gas Cleaning (FGC) Systems is designed to to evaluate, develop, demonstrate, and recommend environmentally acceptable cost-effective techniques for disposal and utilization of FGC wastes, with emphasis on flue gas desulfurization (FGD) waste, and to evaluate and demonstrate systems for maximizing recycling and reuse of power plant water. The program currently consists of 19 projects encompassing 6 major areas of interest: (1) environmental assessment of FGC waste disposal and utilization processes including other power plant effluents, (2) process technology assessment and new technology development, (3) process economic studies, (4) alternative FGC waste disposal methods development, (5) new FGC waste utilization methods development, and (6) development of methods for improving overall power plant water utilization.

The scope of the EPA FGC waste and water pollution control program is depicted in Figure 1 (page 12). Projects concerning coal-pile effluents, fly ash, water, and FGC waste (untreated, treated, and as affected by scrubber operation) span the entire spectrum of the FGC waste characterization and disposal assessment problems.

In this report, the specific projects are discussed separately under their respective primary categories as indicated in Table 1 (page 10). Additional information such as contractor or agency project director, EPA project director, duration, start date, and type of study are provided in Table 2 (page 13).

5.1 ENVIRONMENTAL ASSESSMENT OF FGC WASTE DISPOSAL

Seven environmental assessment projects are currently under way. These include FGC waste characterization studies; laboratory and pilot field studies of disposal techniques for chemically treated FGD sludges; characterization studies of coal-pile drainage, coal ash, and other power plant effluents; and studies of attenuation of FGC waste leachate by soils.

5.1.1 FGC Waste Characterization, Disposal Evaluation, and Transfer of Waste Disposal Technology (The Aerospace Corporation)

The Aerospace Corporation, El Segundo, California, is conducting a broad-based ongoing study directed toward the determination of environmentally sound disposal of solid and liquid wastes produced in FGD processes. The desulfurization processes of interest in this program are the lime, limestone, and double-alkali wet-scrubbing of flue gases produced in the combustion of coal in steam power plants. More specifically, problems associated with FGD waste disposal are being defined, and assessments will be made of the operational feasibility, performance, and costs of current disposal methods.[4-6] In addition, recommendations regarding alternative disposal methods based on the above findings are planned. Annual reports will be issued, of which this is the first, in which FGC waste-related research and development (R&D) activities sponsored or conducted by EPA, Tennessee Valley Authority (TVA), and private industry will be summarized and assessed. Periodic updates by means of papers presented at industry meetings and symposiums are also planned.

The principal tasks of this program include (1) detailed chemical and physical characterizations of desulfurization wastes and process streams; (2) evaluation of the potentially toxic hazards associated with methods of disposal or utilization of desulfurization wastes; (3) evaluation of chemical treatment or conditioning techniques needed to achieve environmentally sound disposal; (4) identification and technical evaluation of environmentally sound disposal methods and associated costs; (5) identification of pertinent state and federal water quality and solid waste disposal criteria and an interpretation of the impact of these criteria on the disposal of desulfurization products; and (6) the planning and support of an EPA FGD waste disposal field evaluation program. The later is reported in Section 5.1.2.

Results of tasks (1) through (5) are reported in References 4 and 5 and are summarized in the following paragraphs.

5.1.1.1 Chemical Characterization of Process Streams

The chemical characterization of process streams from seven utility power plants encompassing a wide range of scrubber system capacity, coal sources, and absorbent were analyzed (Table 5), and the effect of processing variables on system chemistry was assessed.

The chemical characteristics were determined on the basis of the following:

a. In-process variations in scrubber liquor composition
b. Variation in trace metal concentration in FGD waste liquors with time
c. Effect of pH and ionic strength on concentration of liquor constituents
d. Comparison of solute trace elements in FGD waste liquors from limestone, lime, and double-alkali scrubber systems
e. Determination of the trace metal relationship between input materials (e.g., coal and absorbent) and output (scrubber waste solids and liquor)
f. Distribution of trace metals released from coal by the combustion process
g. Comparison of the trace metal content of eastern and western coals and its effect on waste composition.

Table 5. FGD SYSTEMS SAMPLED AS DATA BASE

Power Plant	Scrubber System	Scrubbing Capacity, MW (equiv)	Coal Source	Absorbent
TVA Shawnee Steam Plant	Venturi and spray tower, prototype	10	Eastern	Lime
TVA Shawnee Steam Plant	Turbulent contact absorber, prototype	10	Eastern	Limestone
Arizona Public Service Company, Cholla Power Plant	Flooded-disk scrubber, wetted film absorber	120	Western	Limestone, fly ash
Duquesne Light Company, Phillips Power Station	Single- and dual-stage venturi	410	Eastern	Lime
General Motors Corporation, Chevrolet-Parma Power Plant	Bubble-cap tower	32	Eastern	Soda ash, lime
Southern California Edison, Mohave Generating Station	Turbulent contact absorber, pilot plant	< 1	Western	Limestone
Utah Power and Light Company, Gadsby Station	Venturi, and mobile bed, pilot plant	< 1	Western	Soda ash, lime

5.1.1.1.1 In-Process Variations in Scrubber Liquor Composition

A study was made of the changes occurring in the scrubber liquor process streams, starting from the scrubber effluent to the final filtering or dewatering step. Topics addressed in the evaluation of the results included the following:

a. Systematic increases or decreases in the chemical constituent concentration in the scrubber liquor system circuit

b. Effect of the scrubber process, i.e., limestone, lime, or double-alkali

c. The mechanism involved (synergistic change, coprecipitation, or dissolution of constituents from fly ash)

Data were compiled for all major, minor, and trace constituent analyses for five scrubber systems, with the concentration determined for each constituent, beginning with the scrubber, through intermediate process steps and to the final filtration or clarifying operation. These data included the TVA Shawnee plant turbulent contact absorber (TCA) and the venturi-spray tower systems, the General Motors (GM) Parma, Duquesne Phillips, and Southern California Edison (SCE) Mohave systems.

The overall end-to-end changes in the concentration of each constituent were determined and are summarized in Table 6. On the basis of individual chemical constituents only potassium shows a consistent increase in concentration, while aluminum, iron, silicon, silver, chloride, and sulfite showed a decrease. The remainder were unchanged or responded in a manner too subtle to be clearly discernible as they passed through the process circuit. In the lime and limestone processes, the total dissolved solids (TDS) decreased, and the system pH increased from the scrubber to the point of disposal.

On the whole, many elements appear to be removed in the scrubber bleed system by coprecipitation or scavenging; probably by the

Table 6. NET CHANGE IN SCRUBBER LIQUOR COMPOSITION OF MAJOR, MINOR, AND TRACE CONSTITUENTS BETWEEN INITIAL AND FINAL STAGES IN SCRUBBER SYSTEM

Constituent	Limestone[a]			Lime[a]			Double Alkali[a]		
	Increase	Decrease	No Significant Change (< 20%)	Increase	Decrease	No Significant Change (< 20%)	Increase	Decrease	No Significant Change (< 20%)
Aluminum (Al)		XXX			XX	X			
Antimony (Sb)		X			X	XX			
Arsenic (As)	X	X	XXX		XXX	X			X
Beryllium (Be)		XX	XXX			XXXX			X
Boron (B)					X				
Cadmium (Cd)		X	XXX		XX	XX			X
Calcium (Ca)		XXXX			XX	XX			X
Chromium (Cr)	XX	X	XX	X		XX			X
Cobalt (Co)		X				XX			
Copper (Cu)	XX		XXX	X	XX				X
Iron (Fe)		X			XXX				
Lead (Pb)	XX	XX	X			XXXX			X
Magnesium (Mg)	X	X	XX		X	XX			
Manganese (Mn)				X	X				
Mercury (Hg)		XX				XXX		X	
Nickel (Ni)		X			X	X			
Potassium (K)	XXX			XX			X		
Selenium (Se)	XX		XX		X	XXX		X	
Silicon (Si)					XXX				
Silver (Ag)		X			XX	X			
Sodium (Na)			XXXX			XXX			
Zinc (Zn)	X	XXX	X		XXX	X	X		
Chloride (Cl)		XXXX			XX	XX	X		
Fluoride (F)	XX		X	XX		XX			X
Sulfate (SO_4)			XXXX		XX	XX	X		
Sulfite (SO_3)		XXXX			XXX			X	
TDS		XXXX			XX	X	X		
pH	XXXX			XXXX					X

[a] Each "X" represents a separate sample set.

formation and growth of the sulfate phase resulting from the rapid oxidation of the bisulfite ion. Most of the remaining constituents are unchanged in concentration as they pass through the circuit. Except for the increase in potassium, which is attributed to leaching of fly ash, the concentration of major, minor, and trace constituents in the scrubber liquors tends to decrease along the process circuit.

Chloride ion content is seen as a system variant for all three scrubbing processes, possibly as a consequence of system pH levels. The changes in calcium, sodium, and sulfate concentration in the double-alkali systems are attributed to inherent in-process chemistry.

5.1.1.1.2 Variation in FGD Waste Liquor Composition with Time

To determine if constituents of FGD waste liquors undergo any significant changes in concentration during extended periods of operating time, analyses were made of major and trace constituent levels in the disposal liquor of each set of samples as a function of sampling date. The scrubbing systems selected for this evaluation were those for which multiple sample sets had been analyzed over time periods ranging from 4 to 16 months. These systems were the TVA Shawnee TCA, TVA Shawnee venturi-spray tower, Duquesne Phillips venturi, and the Arizona Public Service Cholla Venturi-absorption tower. In addition, two sample sets were taken that included a sampling shortly after startup of the Shawnee lime process and the Shawnee limestone process.

For the lime process, the first sample set was taken on the third day after startup and the second one was taken about two months later. The other scrubber system sampled during the startup period was the Shawnee limestone process. It was first sampled about six weeks after an intermittent period of operation in an open-loop mode. A second sample set was taken approximately five months later.

On the basis of the sampling rates described for the four power plants evaluated, it appears that a rapid buildup in the concentration of major species takes place and reaches relatively stable conditions at a concentration where the rate of constituent loss in the waste product equals the rate in which that constituent is scrubbed from the flue gas.

After an initial buildup period after startup, the trace elements, except for lead, exhibit no systematic time-related trend in concentration level for the trace constituents of the liquor. Since trace element concentrations did not change systematically with time nor with changes in major species concentration the controlling factor other than saturation chemistry was postulated.

The variation in concentration of a given element from one set of samples to the next was ascribed principally (lead, possibly, being an exception) to the effects of differences in input materials, (fuel absorbed and process water), to operating conditions, and in the case of very low-concentration-level trace metals, to low analytical precision. It should be noted that in some cases where TDS increased because of an increase in sulfate content, the trace elements decreased, but when the TDS increase was caused by chloride ion increase, the trace elements increased. This behavior may suggest that sulfate ion may be exercising some influence on the content of trace elements. Insufficient data are available to provide confirmation of this observation.

For lead, there may be a direct relationship between concentration and time. The buildup of lead implies that a saturation concentration was not reached or that fluctuations in input ingredients were small relative to the concentration in the liquors.

5.1.1.1.3 Effect of pH and Ionic Strength on Concentration of Liquor Constituents

In the evaluation of the chemical analyses discussed previously, a general decrease in trace element content as pH increased was noted. Also, it was observed that TDS (and therefore ionic strength) increased for the duration that the scrubber was operated.

In most scrubber systems, a pH is used as a system control parameter. When data from all the systems were evaluated as a function of pH on a system-by-system basis, no correlation was evident. The conclusion is drawn that trace element concentration of the scrubber liquors within a specific system is not controlled by either system pH or the ionic strength of the liquor. This is in agreement with the results of observations which ascribe trace element concentrations in system liquors to the variations in trace element content of process ingredients and to major system design variables. It is not apparent in any of these analyses that a level of soluble saturation may have been reached by any of the trace elements relative to the major species chemistry.

5.1.1.1.4 Comparison of Solute Trace Elements in FGD Waste Liquors from Limestone, Lime, and Double-Alkali Scrubber Systems

Overall concentration levels of solute trace elements in scrubber liquors using the limestone, lime, and double-alkali processes were evaluated to determine if any appreciable differences existed for the three processes. The results reported showed that, in nearly every case, the trace metals concentrations (As, Be, Cd, Cr, Cu, Hg, Pb, Se, and Zn) are higher in the limestone system and lower in the double-alkali system relative to the lime system. Although there is a range of concentrations and some overlap in the range of trace element concentrations between power plants using different scrubber chemistries, concentration trends were in the order given, with limestone system concentration worst cases being from one to ten times higher and the lime values and double-alkali worst cases being lower by a factor of one to four. The only obvious system parameter that can account for this order of trace metals is scrubber pH, which is lowest in the limestone systems and highest in the double-alkali system.

This basis of comparing scrubbing systems tends to support the conclusion that the determining factors in trace metal levels in liquors are primarily associated with system variables, the amounts entering the system from all sources. System chemistry, in particular pH, has a discernible influence. The effect of other system variables, such as residence time in the circuit and system efficiency as determined by mechanical design, which may contribute to a lesser degree to the concentration of the solute trace metals has not been quantified.

5.1.1.1.5 Determination of the Trace Metal Relationship Between Input Materials (coal and absorbent) and Output (scrubber sludge and liquor)

The relationship between the observed concentration range of trace metals in coal (corrected for absorbent by inclusion as an equivalent coal contert) and in sludge solids is shown in Figure 4. Similarly, Figure 5 illustrates a relationship between the concentrations in sludge liquors and the coal, with the bandwidth being nearly two orders of magnitude. The trace metal concentration in the liquor is approximately two orders of magnitude less than that for the solids, and some of the uncertainty associated with precision at lower concentrations may be reflected in the data scatter. There is no evidence in these results to indicate that trace element concentration is controlled by solubility limitations.

Furthermore, the trace metal content in FGD waste liquors has already been reported to be affected by scrubber pH. If the trace metal content for the sludge liquor were corrected for the differences in pH, a further reduction in data scatter would be expected.

In summary, the trace element content of FGD waste solids and liquors appears to be a function of the trace element content in the process ingredients, particularly coal. Data scatter may be a result of the differing amounts of fly ash in the wastes and the scrubbing efficiency relative to each element. Scatter in the liquor data slo is expected because the pH of the system liquor has been shown to influence the concentration of trace metals in the liquors when one system is compared with another.

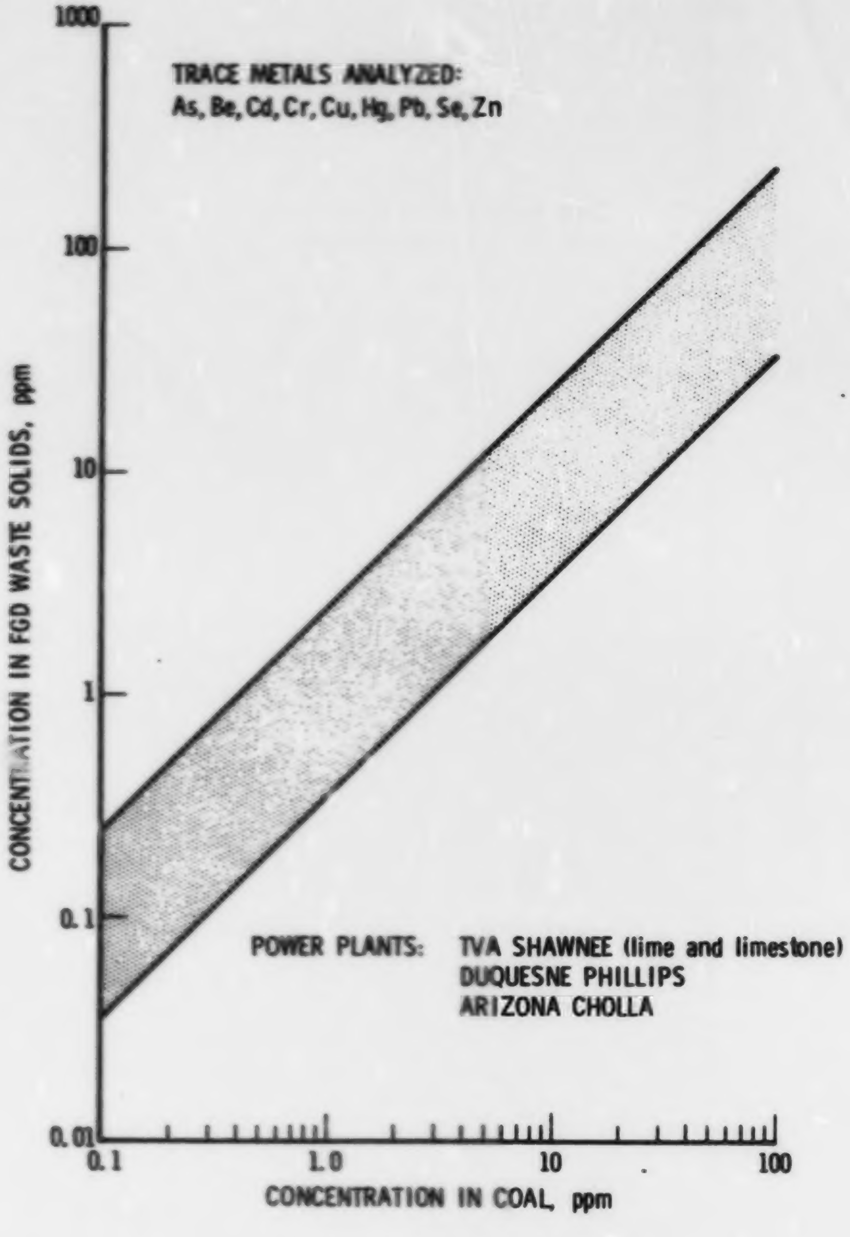


Figure 4. Relationship between trace metal content in coal and FGD waste solids

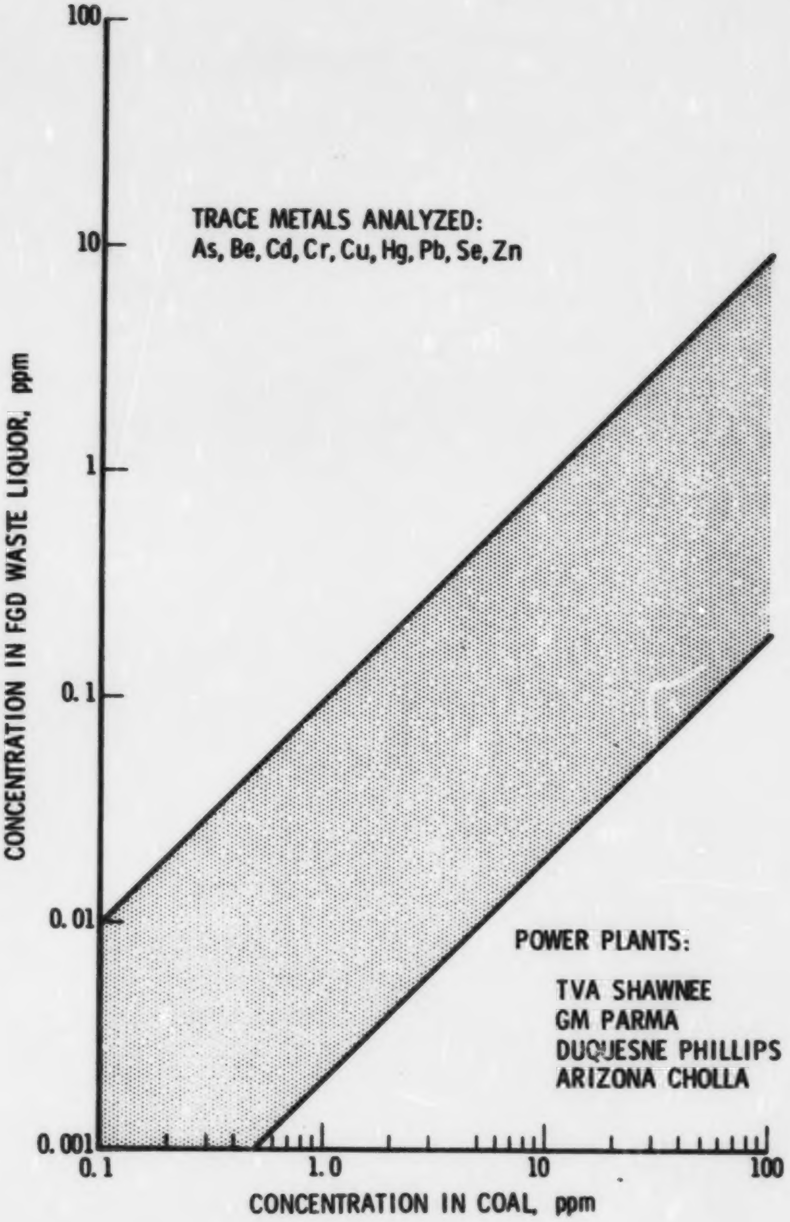


Figure 5. Relationship between trace metal content in coal and FGD waste liquors

5.1.1.1.6 Distribution of Trace Metals Released from Coal by the Combustion Process

In the previous paragraph a correlation was presented that showed the concentration of trace elements in the sludge to be approximately the same as the concentration in the coal. The bandwidth of the data scatter for solids is about one order of magnitude, and the range of fly ash content in the FGC wastes also was reported as about one order of magnitude. Moreover, in evaluating the data bandwidth in Section 5.1.1.1.5, it was reported that wastes with high fly ash content tended to lie on the high side of the data band and that data from low fly ash wastes is more prevalent on the low side of the data band.[5]

The results of this study are consistent with the trace metal distribution studies found in the literature[7-11] and show that the major source of trace metals found in the waste is in the fly ash. Two exceptions are mercury and selenium, which are not found in the fly ash at relative concentrations equivalent to the other trace metals. Both are found primarily in the flue gas stream as vapors or ultrafine particulates ($< 0.1\ \mu m$). However, their relative concentrations in the waste are nearly equivalent to the other trace elements, which infers that some removal from the flue gas occurs. In Section 5.1.1.1.5, it was noted that a small fraction of the trace metals is in the waste liquor, i.e., approximately 1/100 of the concentration that is in the solids. It is postulated that most of these metals originate by leaching from the fly ash during the more acid cycle of the scrubbing operation.

5.1.1.1.7 Comparison of Trace Metal Content from Eastern and Western Coals and Their Effect on Waste Composition

The correlation between trace metals in sludge and coal demonstrated in Section 5.1.1.1.6 suggests that the trace metal content expected in eastern and western scrubbing liquors may differ as a consequence of differences in trace metal content of the coals.

When comparing the coal analyses of this study with other sources,[7-11] it is seen that, with few exceptions, the range of measured values falls within the reported range for each element. These data show that measured values from western coal for arsenic, cadmium, mercury and zinc are lower than the measured values from eastern coals; on the other hand, western coal had high values of copper. These high values may be explained by the proximity of the coal fields studied in this report to a major copper-producing region. No other elements showed significant differences between regions.

5.1.1.2 Leaching Characteristics of Untreated FGD Wastes

A pollution potential may exist as a consequence of the action of rainwater leaching through FGD wastes in an unlined disposal basin. If free-standing water is allowed on the surface, some will permeate through the waste. The amount of water permeating through the waste depends upon the permeability of the waste, the permeability of the subsoil, and the amount of standing resulting from rainfall or from separation from the solids. The quality of the leachate depends on the amount of constituents absorbed in the permeation process.

FGD solid waste normally contains occluded liquor from the scrubbing process representing 35 to 80 percent by weight of the total waste, depending upon the extent of dewatering. Water permeation through the solids flushes most of this occluded liquor within the first three pore volume displacements. Thereafter, the quality of leachate is dependent upon the solubility of the waste solids.

Two sets of leaching experiments were conducted. In the first set, three laboratory columns were packed with wastes obtained from the TVA Shawnee limestone, the Arizona Cholla limestone, the Duquesne Phillips lime, the GM Parma double alkali, and the SCE Mohave limestone processes. Leaching water (unbuffered) adjusted to pH 4, 7, and 9, with either HCl or NaOH, was used in each set of columns. The leaching water and the leachate were allowed to react with air so as to stimulate aerobic conditions. A second set of leaching experiments were conducted under anaerobic conditions. These experiments duplicated the first experiments except that the leaching water and leachate were protected from interaction with the atmosphere and leaching water with a pH 7 was used because no discernible effect was noted between the aerobic columns as a result of differences in the initial pH of the leaching waters.

Whether leaching conditions are aerobic or anaerobic depends upon the sludge and site conditions. Aerobic leaching water can result from supernate equilibrium with the atmosphere; however, subsequent percolation through a sulfite sludge can create an anaerobic condition in the leaching water. The resultant leachate can remain anaerobic in the subsoil; however, if the soil is plugged by filtering of fine and colloidal particles from the sludge and penetration through this filter zone is slower than permeation through the soil, the opportunity exists for the creation of air voids in the soil. In this case, the leachate may become aerobic. In field conditions, all four combinations of aerobic and anaerobic leaching water and leachate are possible.

In both experimental sets, analyses were performed for As, Be, Cd, Cr, Cu, Pb, Hg, Se, Zn, Cl, F, SO_3, SO_4, pH, and TDS as a function of the leachate volume passing through the column.

The detailed results of the leaching experiments are presented in Reference 5. Typical characteristics from the aerobic experiments are shown in Figure 6, which illustrates the effect of leaching through Shawnee limestone waste. For the aerobic test results, a single curve is presented for each species representing the median value of concentration from the three values of pH for leaching water used on each waste type. The curves shown are normalized to the concentration of the first pore volume, which essentially reflects the concentration of the mother liquor.

A typical result of the anaerobic leaching experiments is presented in Figure 7. From an overall assessment of the leaching data, it was concluded that for each of the major species represented by sulfate,

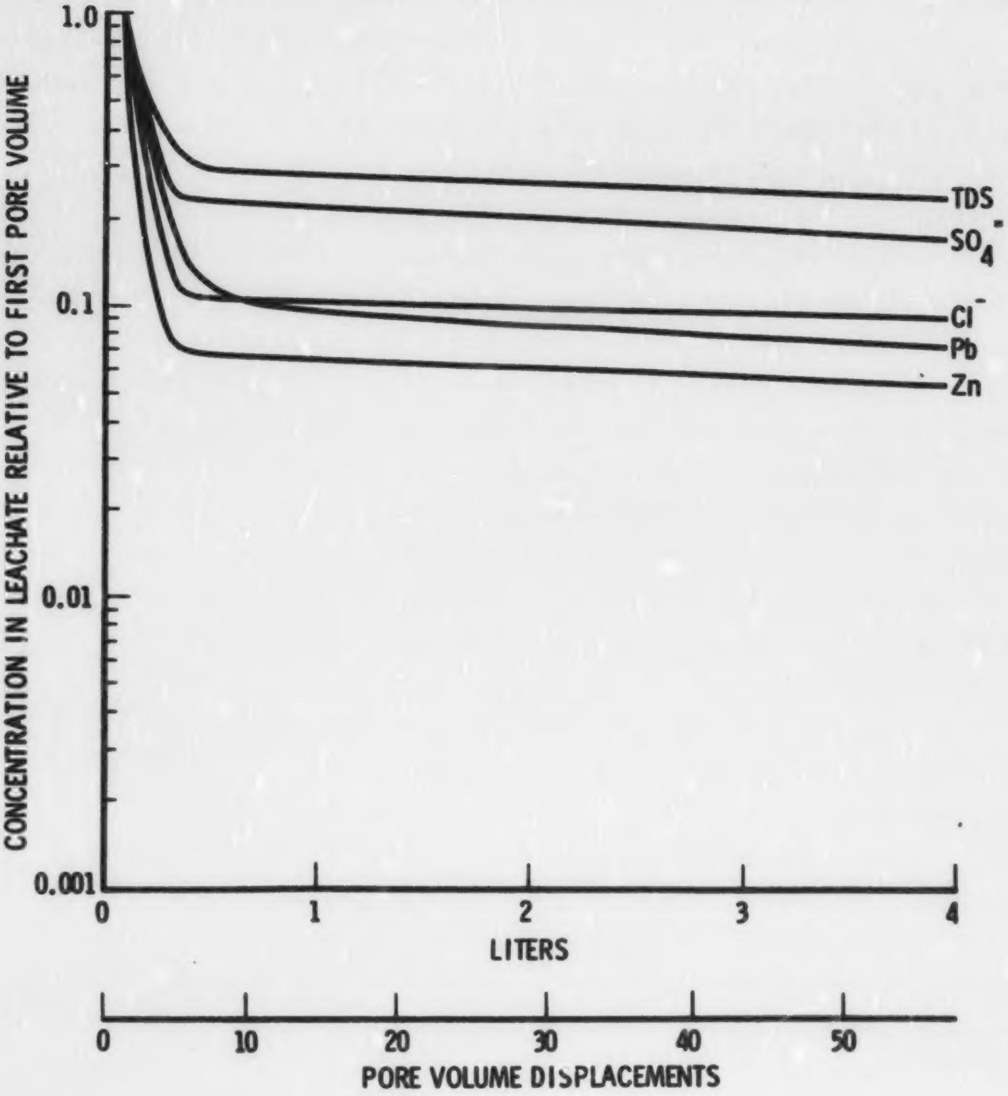


Figure 6. Leachate analyses from TVA Shawnee untreated limestone waste: aerobic conditions

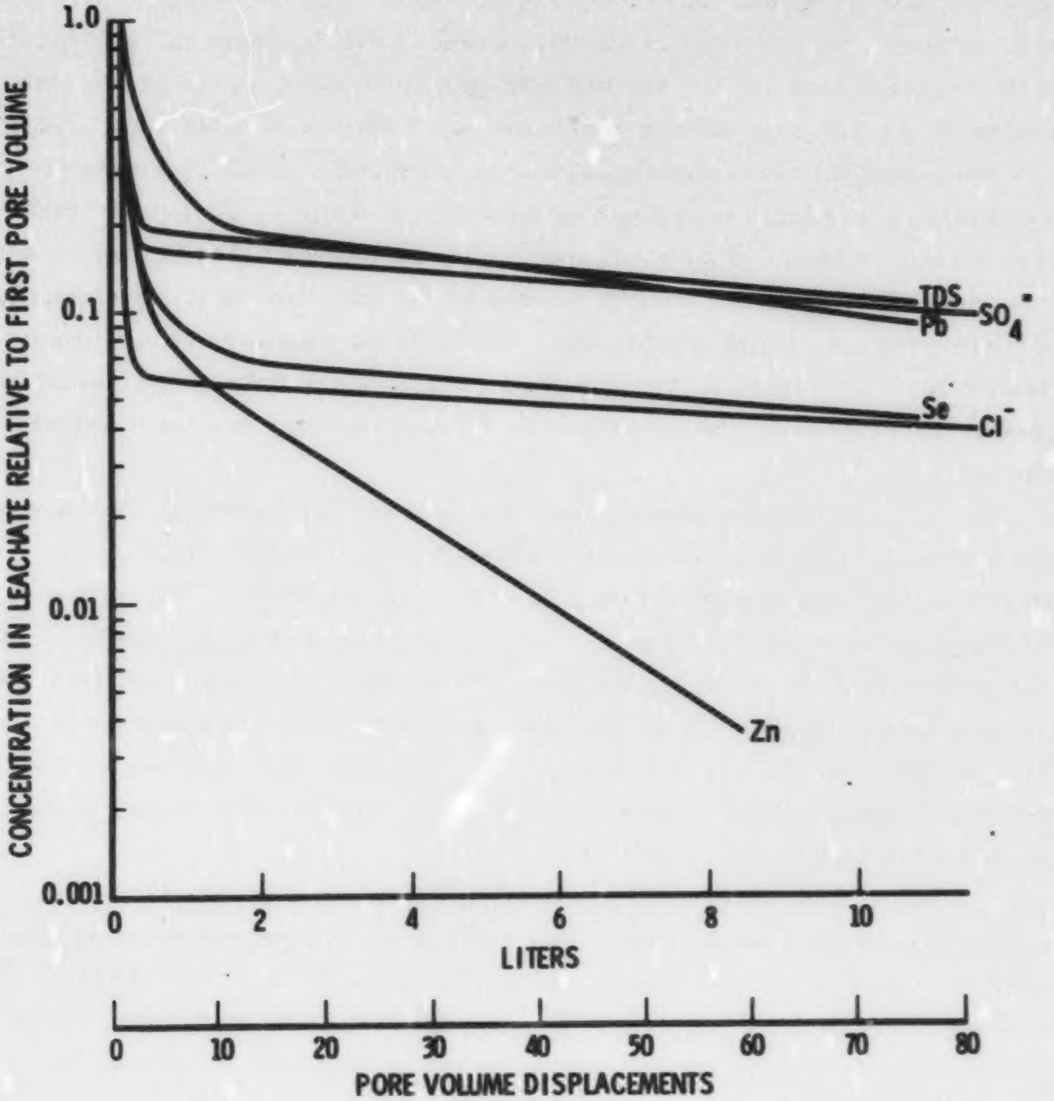


Figure 7. Leachate analyses from TVA Shawnee untreated limestone waste: anaerobic conditions

chloride, and TDS, the concentrations decrease rapidly during the first few pore volumes, and in most cases 90 percent of the decrease in concentration of the leachate between the 1st and 50th pore volume occurred at the completion of the 3rd pore volume displacement. When a similar comparison was attempted for trace metals, it was noted that for some elements the transition period from pore flushing to solids dissolution generally extended over a greater range of pore volume displacements than that for major constituents. This behavior may be caused by the presence of these elements in trace amounts, which would result in a reduced flushing action from a given volume of water, or the observed behavior may only be the result of greater uncertainty in the analytical data because of the low trace metal concentration.

When comparing aerobic and anaerobic leaching, it appears that a greater drop in concentration of major constituents occurs in the anaerobic leaching condition than in the aerobic conditions. Moreover, when compared with the mother liquor,[5] the concentration of major species in the 50th pore volume is consistently less for anaerobic leaching conditions than for aerobic conditions. When the same comparison is attempted for the trace metals, no lear trend was reported except for lead. In every case, lead concentration in the 50th pore volume was significantly higher when leached under anaerobic conditions.

When the leaching effect on major species was assessed, certain generalities were made. The sulfate ion concentration in the aerobic columns, after 50 pore volume displacements reached a constant value between 1100 and 1300 mg/ℓ, and was independent of the concentration of the mother liquor. Sulfate ion concentration in the 50th pore volume in the anaerobic columns showed a consistent 20 percent lower value that ranged between 900 and 1100 mg/ℓ. In the 50th pore volume, the chloride concentration was found to have stabilized between 95 and 130 mg/ℓ in the aerobic columns and about one-half of that value in the anaerobic columns.

5.1.1.3 Leaching of Chemically Treated Waste

Leaching experiments were also conducted with treated FGD wastes under both aerobic and anaerobic conditions. Generally the aerobic and anaerobic leaching conditions were similar to those for the untreated wastes. However, the chemically treated sludge was dried and pulverized before packing into the leaching column so that the maximum surface contact area was available for the flow of water through the treated sludge.

The results of leaching experiments for various processes and power plant sites are given in Reference 5. Typical aerobic and anaerobic results for one chemical treatment process for Shawnee limestone wastes are shown in Figures 8 and 9.

The results reveal leaching profiles (as a function of pore volume) similar to those observed in the leaching of untreated FGD waste. In most cases, the decrease in concentration of chemical species in the leachate takes place within the first few pore volume displacements. However, contrary to untreated FGD waste leaching experience, the rate of decrease in concentration of some of the major chemical species was more gradual. In the leaching of untreated waste, a greater rate of decrease in concentration was observed in leaching under anaerobic condition. In assessing the results obtained from the leaching of wastes treated by either the Chemfix, Dravo, or IUCS processes, it was concluded that the type of conditions, i.e., aerobic vs anaerobic, would not be a significant factor in the selection of a particular chemical treatment process.

Chemical treatment generally improves leachate quality, dependent almost completely on the specific waste and the specific chemical process used. The concentration of the major chemical species in the leachate from the chemically treated waste are approximately 1/4 to 1/2 the concentration in the leachate from untreated waste.

When the results are examined for effect on trace metals, it is not apparent that chemical treatment of FGD waste improves the leachate quality. In those cases in which high initial concentration of trace metals

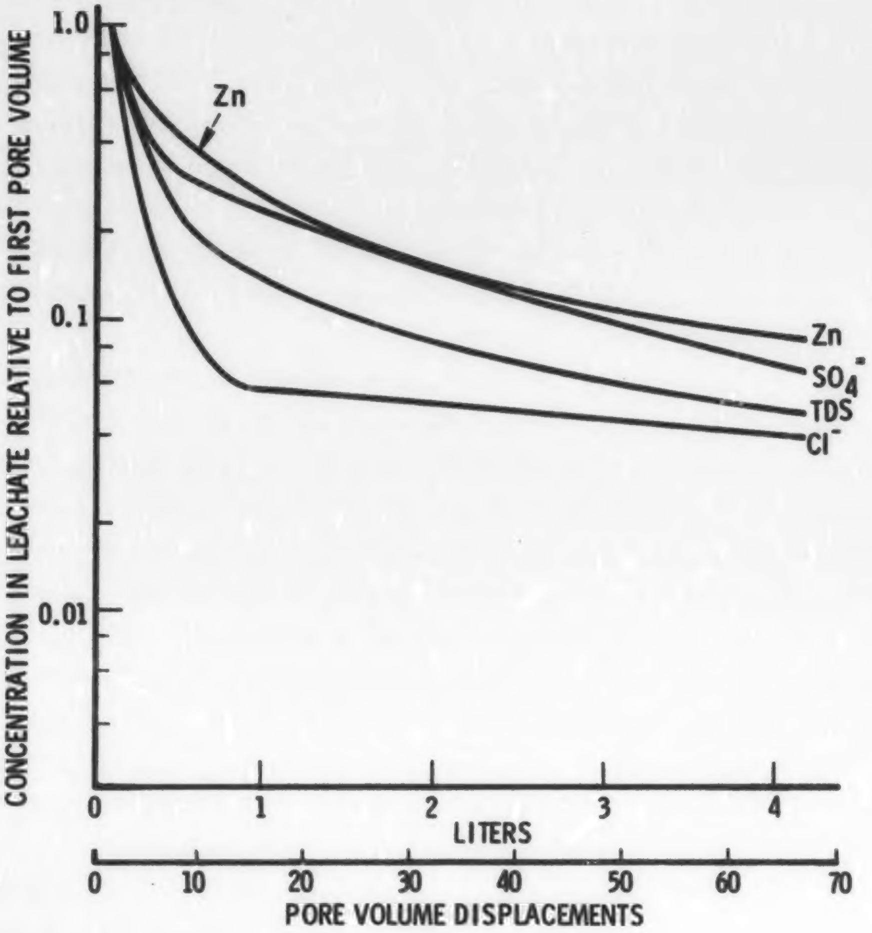


Figure 8. Leachate analyses from TVA Shawnee treated limestone waste (Chemfix): aerobic conditions

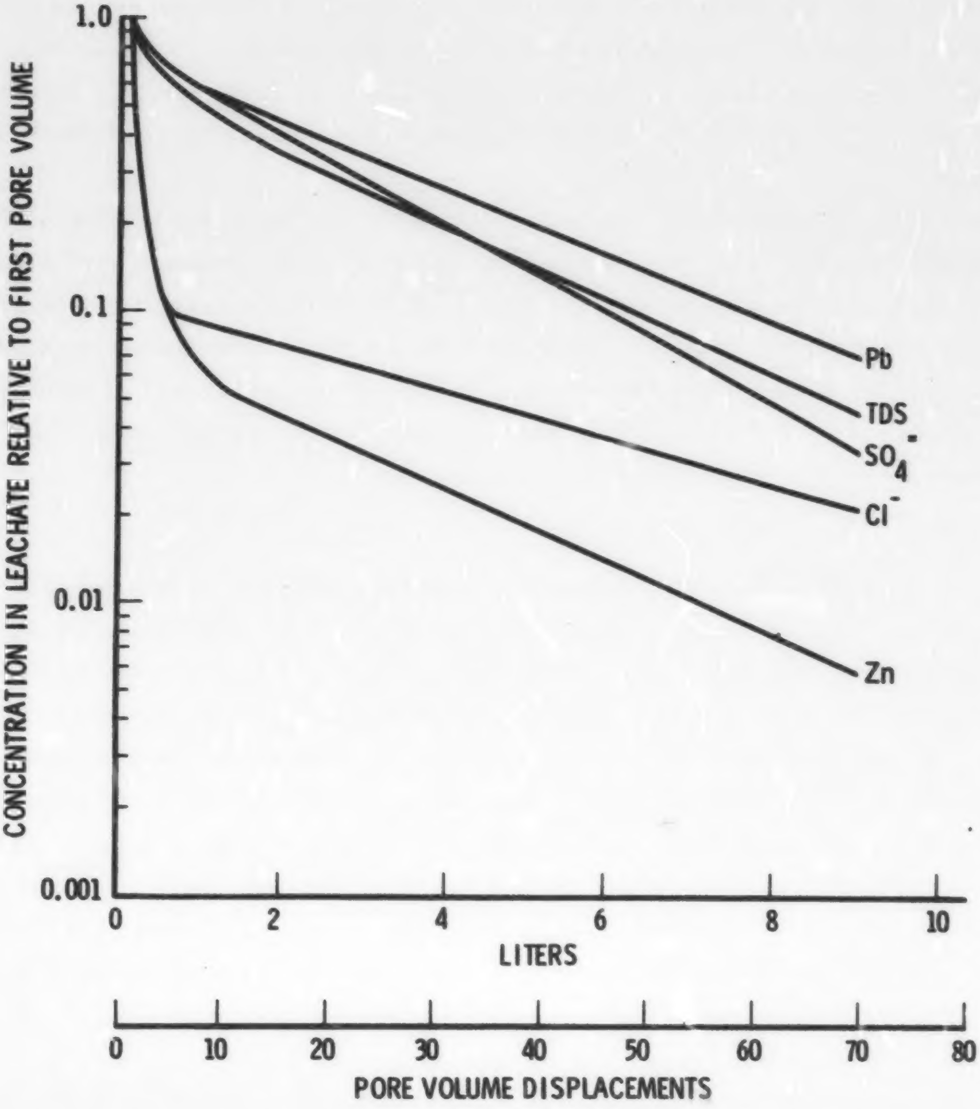


Figure 9. Leachate analyses from TVA Shawnee treated limestone waste (Chemfix): anaerobic conditions

appeared in the leachate of untreated waste, similar concentrations were measured when the sludge was chemically treated. This response was similar under aerobic and anaerobic leaching conditions. This may be partially explained that in some cases there is evidence to suggest the chemical additives used in the fixation process are contributing trace metals to the leachate.

In summary, chemical treatment by the methods evaluated in this study do not tend to reduce leachate concentrations of trace elements, but do reduce concentrations of the major species by a factor of two to four relative to untreated wastes. However, other effects resulting from chemical treatment, such as reduced permeability and superior disposal placement techniques, are considered significant in reducing the release rate of all the constituents to the soil beneath the treated waste.

5.1.1.4 Physical Properties

The disposal, handling, and transportation techniques for FGD wastes will be strongly influenced by the physical behavior of these wastes and the resultant costs. The applicability of some of these techniques may be limited or restricted by physical properties of FGD wastes in the particular state in which they are produced, i.e., degree of water content, crystalline phase composition, and particle size and distribution. Experimental tests were conducted to characterize the FGD wastes of seven power plant scrubbing facilities, which include pilot, prototype, and full-scale units ranging from 1- to 410-MW equivalent capacities. In each case, the FGD waste studied was the waste material for each facility and received in its normal state of disposal. The testing was directed toward the application of the results in landfilling and land reclamation situations.

The physical parameters investigated included specific gravity and bulk density as a function of solids content, water retention as a function or dewatering techniques, viscosity of slurries at various solids contents, permeability as a function of particle packing, and compactibility and unconfined compressive strength as a function of solids content.

5.1.1.4.1 Solids Characterization

The physical properties of any liquid-solid mixture are dependent upon the characteristics of both the liquid and the solid constituents as well as the interaction between them. The FGD wastes contain four principal crystalline phases: calcium sulfite, calcium sulfate, fly ash, and unreacted limestone or precipitated calcium carbonate. These solid phases exist as fine particulates suspended in an aqueous liquor which is usually saturated with ions of these solids. In addition, sodium chloride or calcium chloride is also present as a dissolved salt.

The relative amounts of each of the solid crystalline phases are dependent upon many system design parameters and include (1) the sulfur content of the coal and the efficiency of scrubbing SO_2, (2) the fly ash in the flue gas entering the scrubber and the fly ash removal efficiency of the system, (3) the stoichiometric ratio of reactants added relative to the sulfur content and the reactant utilization efficiency, and (4) the amount of oxidation of the sulfur products that takes place in the system. In addition, each crystalline phase and the characteristic of each phase will have some influence on the behavior of the waste.

5.1.1.4.2 X-Ray Diffraction Characterization

The objective for the use of x-ray diffraction techniques to examine power plant FGD wastes was to provide quantitative characterization of the crystalline phases in the solid waste. The study indicated that although this method was not suitable for quantitative analyses, it permitted a determination of the relative concentrations of the major constituents within a given waste.

The results of the x-ray study showed that in most cases several calcium sulfate-sulfite phases were present, in addition to the expected phases of gypsum and calcium sulfite hemihydrate.

The Shawnee limestone waste showed strong gypsum peaks, as expected, but there was also evidence of a second calcium sulfate dihydrate that appeared as a weak phase in at least two samples. This second phase is a relatively newly discovered phase which, while having many crystallographic similarities to gypsum, it is nevertheless a unique phase, and the consequences of its presence is unknown at present. The calcium sulfite hemihydrate in all cases was the second most prominent phase in the x-ray patterns, appearing as a moderately strong phase. In addition, a calcium thiosulfate hydrate phase appeared as a weak phase, and residual limestone (calcite) appeared also as a weak phase in all samples. The other samples are discussed in detail in Reference 5.

In summary, the x-ray diffraction characterization, while not providing quantitative data, provides insights that are helpful in identifying phases in the waste that could not otherwise be determined and, further, provides semiquantitative data relative to the amount of the phases present.

5.1.1.4.3 Solids Composition

The composition of the solids fraction of each of the wastes sampled was determined by chemical means and is presented in Table 7. The analytical techniques used are described in Reference 5. The wide range in composition for each of the major solid constituents reflects the various design differences that exist among scrubber systems. Systems having high-efficiency fly ash collection facilities upstream of the scrubber are contrasted sharply with those systems having less efficient collection methods. The calcium sulfate content of the sludge reflects in each case the capability of the calcium sulfite to be oxidized, this reaction usually occuring in the scrubber or reaction tank.

5.1.1.4.4 Crystalline Structure

A portion of waste solids from each scrubber facility was selected for subsequent examination on the scanning electron microscope (SEM), from the materials prepared for x-ray characterization. A series

Table 7. PHASE COMPOSITION OF FGD WASTE SOLIDS IN WEIGHT PERCENT[a]

Atomic Formula	TVA Shawnee Limestone, 2/1/73	TVA Shawnee Limestone, 7/12/73	TVA Shawnee Limestone, 6/15/74	TVA Shawnee Lime, 3/19/74	SCE Mohave Limestone, 3/30/73	GM Parma Double Alkali, 7/17/74	APS Cholla Limestone, 4/1/74	DLC Phillips Lime, 6/17/74	UPL Gadsby Double Alkali, 8/9/74
$CaSO_4 \cdot 2H_2O$	21.9	15.4	31.2	6.3	84.6	48.3	17.3	19.0	63.8
$CaSO_3 \cdot 1/2H_2O$	18.5	21.4	21.8	48.8	8.0	12.9	10.8	12.9	0.2
$CaSO_4 \cdot 1/2H_2O$						19.2			
$CaCO_3$	38.7	20.2	4.5	2.5	6.3	7.7	2.5	0.2	10.8
$MgSO_4 \cdot 6H_2O$	4.6	3.7	1.9	1.9					
$CaS_2O_3 \cdot 6H_2O^a$							14.3		
$Na_2SO_4 \cdot 7H_2O$						6.9			
NaCl					1.5				
$CaSO_4^a$									17.7
$CaS_3O_{10}^a$								9.8	
Fly Ash	20.1	40.9	40.1	40.5	3.0	7.4	58.7	59.7	8.6
Total	103.8	101.6	99.5	100.0	103.4	101.4	103.6	101.3	101.1

[a] Phases not explicitly measured; presence deduced from x-ray study.

of photomicrographs were taken of each sample to assist in interpreting the results of the various other chemical and physical characterization tests. A typical example of the crystalline structure of the solids content is shown in Figure 10, which shows a distribution of particles representing the solids content of the TVA Shawnee TCA system sludge using limestone absorbent. The waste is characterized by large platelets of calcium sulfite hemihydrate and spherical fly ash particles. A broad range of particle sizes exists for both phases, with fly ash particles in the range of 0.1- to 50-μm diameter. The calcium sulfite phase is present as stacks of platelets with edge dimensions as large as 20 to 50 μm for the largest particles and platelet thickness of approximately 0.1 to 0.5 μm. In addition to these two phases, large particles of residual limestone and blocky sulfate particles are occasionally seen, but these are seldom greater than 5 μm in the longest dimension.

5.1.1.4.5 Viscosity

The viscosity of the liquid waste is a direct measure of its pumpability, which affects both the cost of transporting it as well as the system design. Waste materials produced in FGD systems contain finely divided particulate materials suspended in an aqueous medium. Sulfur waste products (both sulfate and sulfite) tend to have particle sizes in the same range as fly ash, between 1 and 100 μm. Although fly ash is produced in spheres, sulfite wastes are platey and sulfates are blocky in shape. Unreacted limestone (or lime) is usually present in the waste and contributes an additional shape parameter. The particle shape, particularly the platey sulfite, has been credited for the thixotropic nature observed in FGD wastes. Fly ash when present in FGD wastes can provide a marked measure of fluidity that the sludge would not otherwise have.

The viscosity of FGD waste from seven power plants as a function of solids content is presented in Figure 11. The results show that among the sludge tested, pumpable mixtures (< 20 poise) range from a high solids content of 70 percent for the Cholla sample to a low solids content of

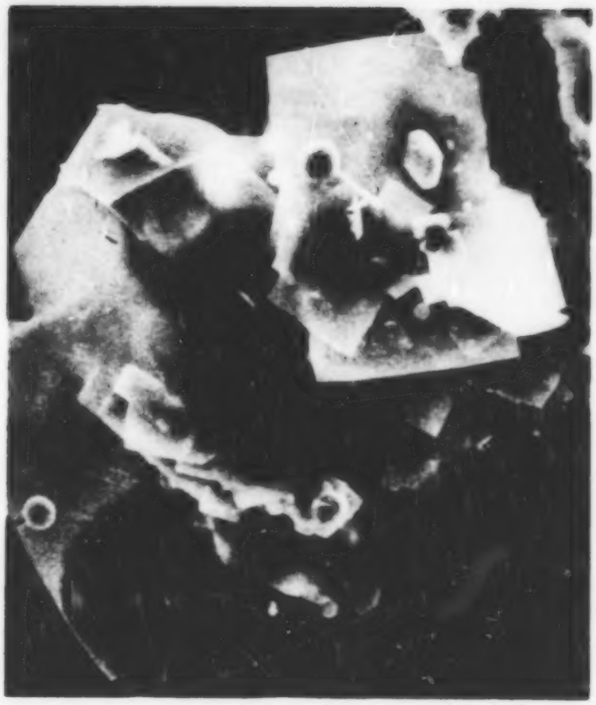


Figure 10. TVA Shawnee Limestone clarifier underflow crystal structure (3000×)

CURVE	SOURCE	DATE	FLY ASH, %
①	ARIZONA CHOLLA LIMESTONE	4/1/74	58.7
②	SCE MOHAVE LIMESTONE	3/30/73	3.0
③	TVA SHAWNEE LIMESTONE	7/11/73	40.9
④	TVA SHAWNEE LIMESTONE	6/15/74	40.1
⑤	TVA SHAWNEE LIMESTONE	2/1/73	20.1
⑥	DUQUESNE PHILLIPS LIME	6/17/74	59.7
⑦	TVA SHAWNEE LIME	3/19/74	40.5
⑧	UTAH GADSBY DOUBLE ALKALI	8/9/74	8.6
⑨	GM PARMA DOUBLE ALKALI	7/18/74	7.4

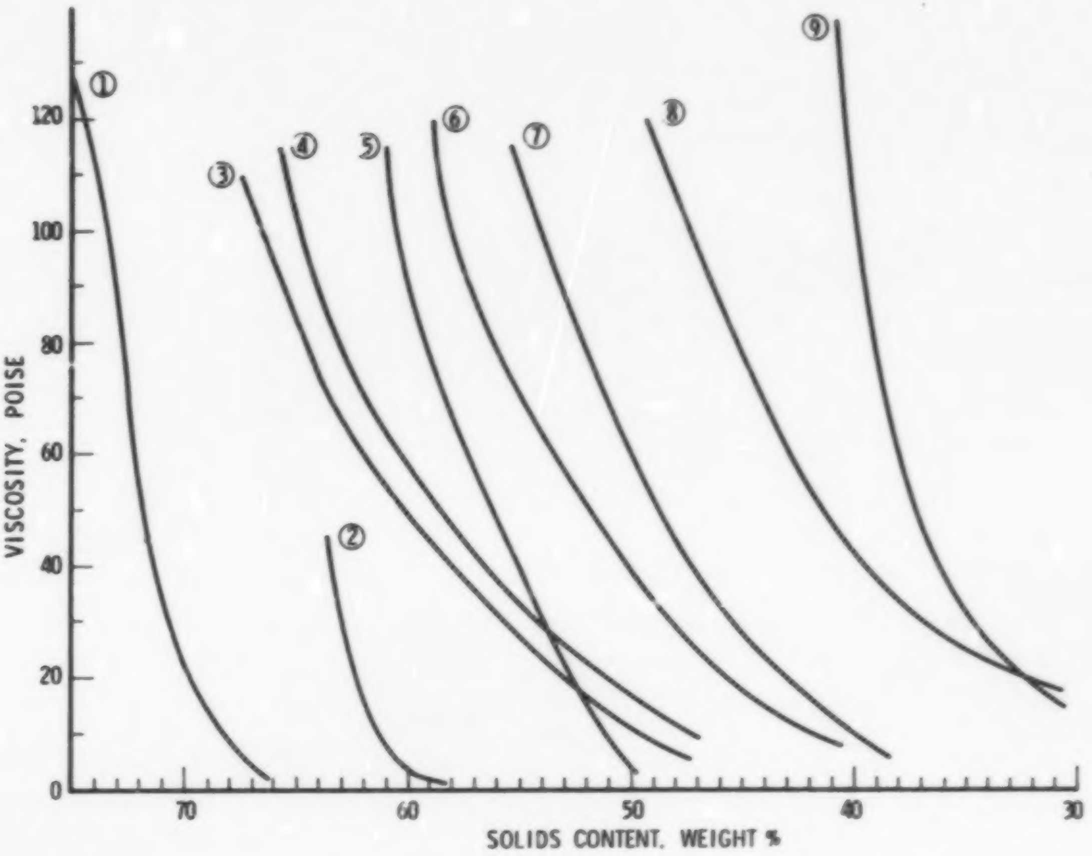


Figure 11. Viscosity of FGD wastes

32 percent for both the Utah Gadsby and GM Parma samples; a total range of 38 percent solids content. Considering this wide spread, the importance of experimentally determined data for system design parameters is apparent.

The slope of the viscosity curves as a function of solids content lie in two groups: The lower slope group includes all wastes from the TVA Shawnee and the Utah Gadsby facilities; the higher slope group includes the other wastes. Presently, no parameter or set of parameters has been identified to determine responsibility for this behavior.

Thus far, the results of the tests suggest that fly ash decreases the viscosity of FGD wastes. Particle shape, size, and distribution may influence viscosity, but the effect is indeterminant at present.

5.1.1.4.6 Wet Bulk Densities

The ability of a sludge to be dewatered is a function of many variables; the size and distribution of particles, and the crystalline structure of the particles and the method used. Primarily dewatering by clarifiers or thickeners separate water from a slurry, principally through the action of gravitational forces. The secondary methods of dewatering are typically vacuum filtration and centrifugation. In some cases, natural settling may be considered a cost-effective method. Dewatering of power plant FGD waste may be advantageous on the basis of over all disposal costs as well as environmental considerations.

The effectiveness of a dewatering operation is best measured by the relative quantity of water that remains with the solid after performing the dewatering operation. The wet bulk density of a sludge, as reported, is the weight of a unit volume of dewatered sludge containing both liquid and solid phases.

The wet bulk density was determined on eight FGD waste samples after each was dewatered by settling, settling with free drainage, vacuum filtration, and centrifugation (Table 8). A typical set of results is plotted in Figure 12. Data from the laboratory tests indicate that for a major portion of the wastes tested highest density is obtained using vacuum-assisted

Table 8. DEWATERED BULK DENSITIES OF FGD WASTES

Sample Source and Date	Dewatering Method							
	Settled		Settled and Drained		Centrifuge		Filter	
	Percent Solids	Density, g/cc	Percent Solids	Density, g/cc	Percent Solids	Density, g/cc	Percent Solids	Density, g/cc
Shawnee Limestone, 2/1/73	49.0	1.45	55.7	1.51	59.8	1.56	65.0	1.65
Shawnee Limestone, 6/15/74	52.9	1.46	58.3	1.53	63.3	1.60	65.9	1.64
Shawnee Lime, 3/19/74	41.5	1.34	43.4	1.36	49.9	1.44	56.0	1.51
GM Double Alkali, 7/18/74	40.0	1.31	43.9	1.35	50.9	1.43	57.8	1.52
Utah Double Alkali, 8/9/74	37.2	1.30	41.4	1.33	62.2	1.62	54.6	1.50
Duquesne Lime, 6/17/74	47.6	1.40	53.1	1.48	57.2	1.52	57.0	1.52
Cholla Limestone, 9/1/74	46.7	1.39	50.9	1.44	60.9	1.58	53.4	1.48
Mohave Limestone, 3/30/73	66.6	1.65	67.2	1.67	77.0	1.86	80.3	1.78

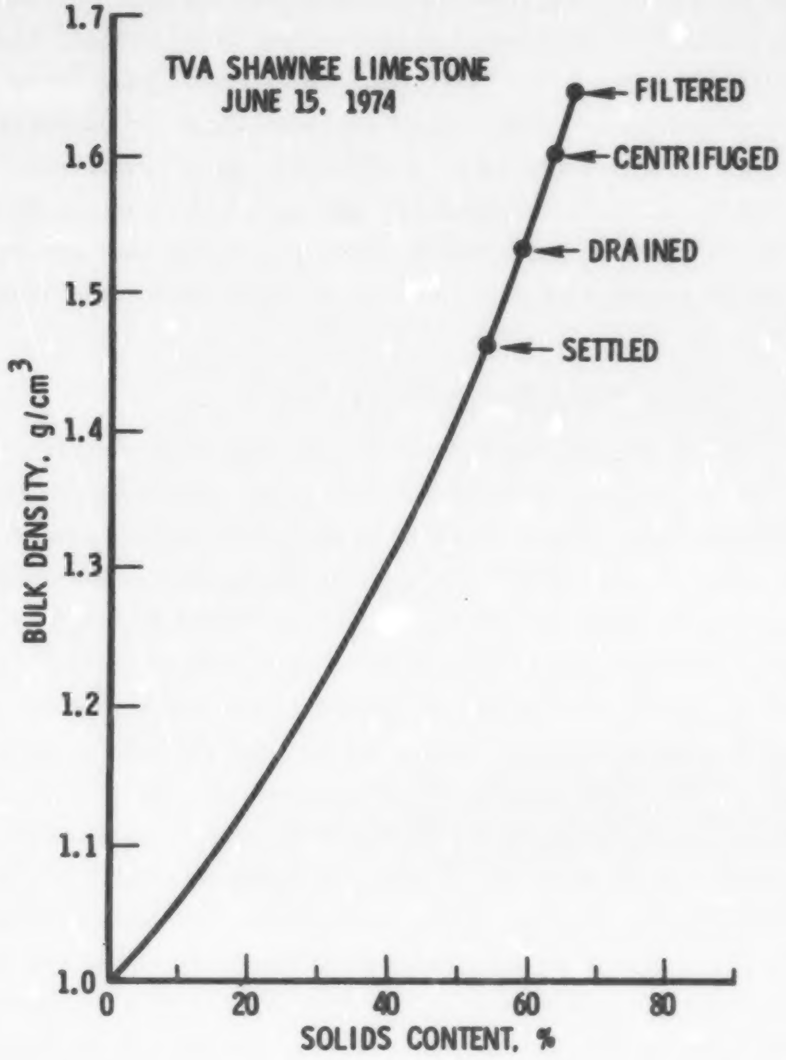


Figure 12. Wet bulk density of FGD waste sample

filtration and in the remaining centrifugation produces the most dense material. These data reveal that the sludges with the best overall dewatering characteristics; the TVA Shawnee limestone, the SCE Mohave, and the Duquesne Phillips sludges, are those with the coarsest particle size distributions. Conversely, the double-alkali systems which produce the finest particle size distributions are those that dewater least efficiently. Although the overall most effective method of dewatering was by vacuum assisted filtration, the tests were conducted with laboratory equipment and the results may not be representative of what may be expected when using commercial equipment.

5.1.1.4.7 Coefficient of Permeability

Since the permeability of FGD waste is a significant factor affecting the seepage of leachate through the waste and the pollution potential of a waste disposal site, the coefficient of permeability of each of the untreated FGD sludges and treated sludges was measured. The permeability of sludge from seven separate scrubbing facilities was determined by passing deionized water through columns containing scrubber waste.

Prior to permeation measurements, the particle packing density was determined from the weight of the charge and the height of the packed column. The pore volume, which is used as a descriptive characteristic, is defined as one minus the solids volume fraction. Untreated waste was compacted after the initial permeation measurement. After a new particle packing density and pore volume were determined, the permeation rate was than measured. The results are tabulated in Table 9 and plotted in Figure 13.

Preparation of chemically treated samples included crushing and pulverizing the fixed material after drying and packing the powder into a column. Although this technique may not apply directly to treated sludge placed and undisturbed at a disposal site, it simulates the maximum sludge that is moved and/or disturbed in a disposal site after placing and curing. Additionally, permeability of undisturbed fixed sludges was determined.

Table 9. PERMEABILITY OF UNTREATED AND CHEMICALLY FIXED FGC WASTES

Sample Source	Sample Date	Replications[a]	Fractional Void Volume	Permeability Coefficient, cm/sec	Remarks
Shawnee Limestone	2/1/73	1	0.69	2.3×10^{-4}	Column packed as slurry
	6/15/74	3	0.60	1.0×10^{-4}	
	6/15/74	1	0.58	9.6×10^{-5}	
	6/15/74	3	0.58	8.5×10^{-5}	
	6/15/74	3	0.55	5.9×10^{-5}	Compacted wet
Shawnee Lime	3/19/74	1	0.75	1.7×10^{-4}	
	3/19/74	1	0.74	5.3×10^{-5}	Compacted wet
	3/19/74	(2)	0.72	6.0×10^{-5}	
Mohave	3/30/73	(3)	0.47	5.0×10^{-4}	Column packed as slurry
	3/30/73	3	0.43	7.5×10^{-4}	
	3/30/73	3	0.34	1.6×10^{-4}	
Dusquesne	6/17/74	(2)	0.68	1.2×15^{-4}	
	6/17/74	3	0.58	1.3×10^{-4}	
	6/17/74	2	0.49	7.4×10^{-5}	
GM Double Alkali	7/18/74	(2)	0.71	8.2×10^{-5}	
	7/18/74	1	0.69	2.5×10^{-4}	
	7/18/74	1	0.65	8.1×10^{-5}	Compacted wet
Cholla	4/1/74	(2)	0.56	2.7×10^{-5}	
	4/1/74	1	0.54	1.8×10^{-5}	
	4/1/74	1	0.54	1.1×10^{-5}	Compacted wet
Utah Double Alkali	8/9/74	1	0.75	9.8×10^{-4}	
	8/9/74	1	0.73	1.3×10^{-4}	Compacted wet
	8/9/74	(2)	0.70	1.2×10^{-4}	
Shawnee Limestone (IUCS)		(2)	0.69	2.2×10^{-4}	Pulverized
Shawnee Limestone (IUCS)		(5)	0.54	5.5×10^{-8}	Solid, undisturbed
Mohave (IUCS)		(2)	0.55	7.9×10^{-5}	Pulverized
		1	0.65	7.3×10^{-4}	Pulverized
		1	0.53	1.9×10^{-4}	Pulverized, compacted wet
Shawnee Lime (IUCS)	5/29/75	1	0.57	5.5×10^{-5}	Solid, undisturbed
	6/12/75	1	-	5.5×10^{-7}	Solid, undisturbed
Shawnee Limestone (Chemfix)		(2)	0.68	4.1×10^{-5}	Pulverized
		1	0.72	$1.5\text{-}2.1 \times 10^{-5}$	Solid, undisturbed
	2/27/75	1	0.70	4.7×10^{-5}	Pulverized
Shawnee (Dravo)		1	0.78	3.2×10^{-4}	Pulverized
	6/12/75	1	0.75	6.9×10^{-5}	Solid, undisturbed
Duquesne (Calcilox)		(2)	0.70	3.8×10^{-4}	Pulverized
		1	0.78	4.9×10^{-4}	Pulverized
		1	0.76	2.1×10^{-4}	Pulverized, compacted wet

[a] Replications of those in parenthesis refer to multiple measurements on a single column using varying hydraulic heads.

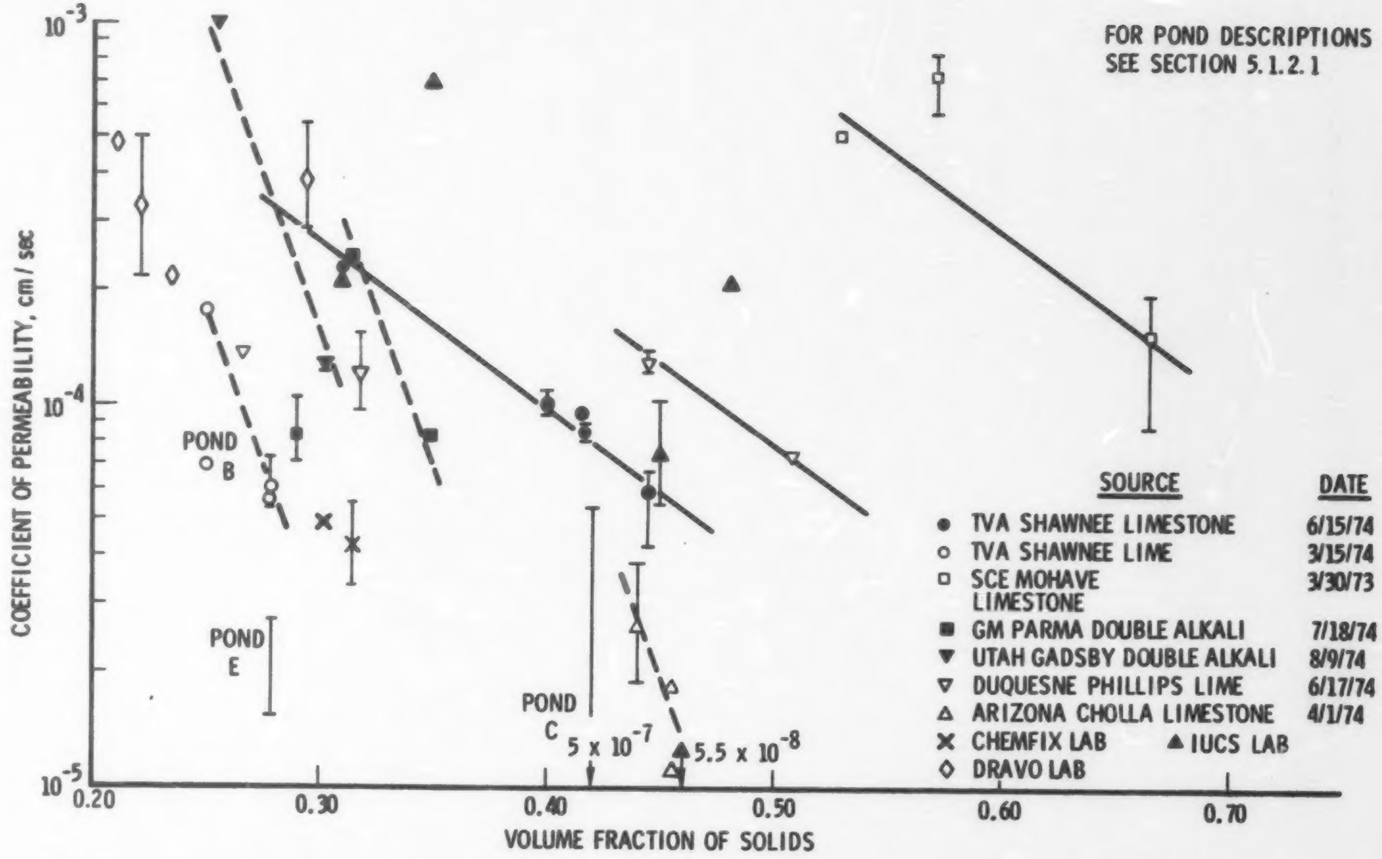


Figure 13. Permeability of untreated and treated FGD wastes

The data presented in Figure 13 illustrate that the permeability coefficient of untreated wastes generally falls in the range of 2×10^{-4} to 1×10^{-5} cm/sec. (Data published by the U.S. Army Waterways Experiment Station (WES) indicate the permeability of similar untreated wastes to be in the range of 8×10^{-5} to 1×10^{-5} cm/sec.[12]) For the crushed treated waste, a range comparable to the untreated material was measured in the Aerospace experiments. However, solid undisturbed treated wastes indicated lower permeabilities by a factor of approximately two to several orders of magnitude (Table 9). (For similar wastes, WES data from Reference 12 show a factor of about two higher to two orders of magnitude lower permeabilities for solid, fixed sludges when compared to untreated wastes.)

Results indicate that chemical treatment tends to reduce the permeability, and that fracturing and crushing of the treated wastes in the field will increase the permeability by some factor, depending on the degree of fracturing. Also, it has been reported informally by several sources that weathering (freeze-thaw cycling) of the treated wastes tends to induce cracks in the material. Therefore, the permeability will be affected to some extent by the depth to which the freeze extends.

5.1.1.4.8 Compressibility Compaction Characteristics of FGC Wastes

An important consideration in the disposal of FGD sludges is the volume or land area required. Therefore consideration of mechanical compaction of the FGC waste to reduce its volume is one of the factors involved in the economics of disposal.

Typical compaction behavior of TVA Shawnee limestone waste is shown in Figure 14. Three nominal values of 79, 86, and 93 percent solids content were selected. The results show that the amount of water in the samples had a marked effect on the compaction that occurred under load. In general, the most compaction (~15 percent), took place at the lowest

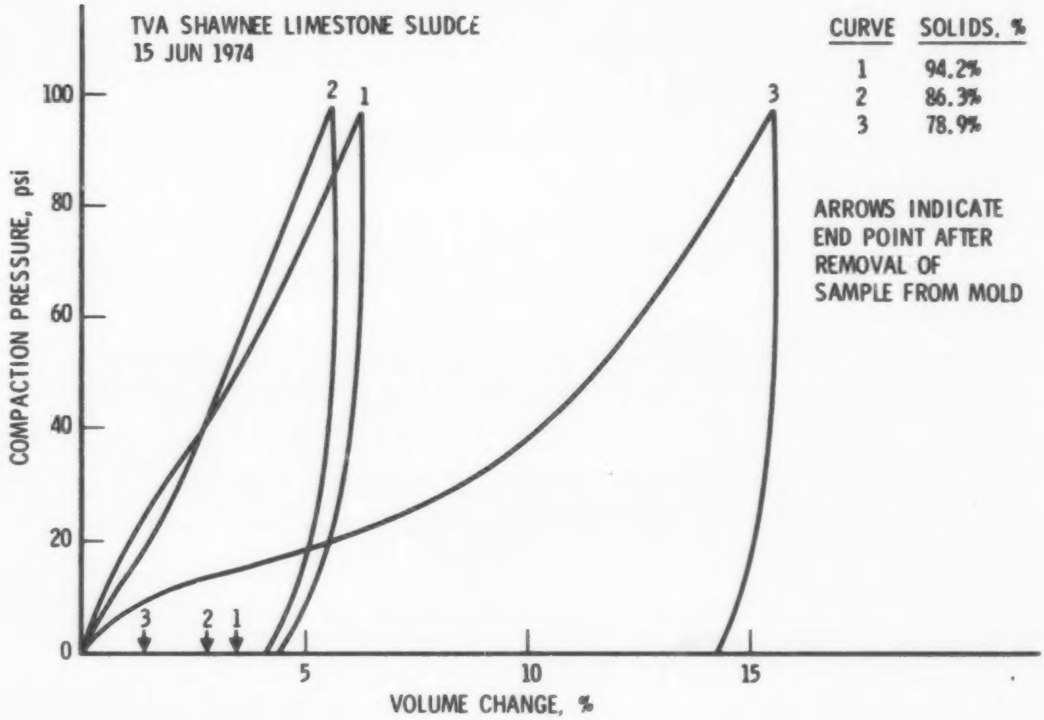


Figure 14. Compressibility characteristics of TVA Shawnee limestone, untreated FGC waste, June 15, 1974

solids content, and the least compaction (~5 percent) took place at the highest solids content. Upon release of the compaction load, the resultant permanent change was 1 to 3 percent (Figure 14). Data for five other wastes from TVA Shawnee (lime), Arizona Cholla, Duquesne Phillips, GM Parma, and Utah Gadsby are given in Reference 5.

An explanation of the behavior observed relates to the crystalline structure of the wastes. When a stress is applied to packed particles having the platey calcium sulfite crystals they bend and deflect. The particles tend to return to their original configuration when the stress is removed. For lath-like gypsum crystals, the growth trend is to form intergrown crystals, with the result being a loosely packed, open network of crystals. The presence of fly ash in the sludge tends to fill the voids between the crystals. Force applied to this arrangement of particles flexes the gypsum crystals and possibly breaks the intergrown clusters; however, increased particle packing is difficult. Only in those cases where particles are reasonably blocky does effective packing take place. Among the six sludges tested, this took place only in the GM Parma and the Arizona Cholla samples.

Criteria for safe access to a pond by personnel or equipment or for land reclamation potential may be based on the load bearing strength of the waste. The parameter most significantly affecting the strength of a given waste is its solids content; therefore, measurements were made to correlate load bearing strength as a function of solids content.[5]

Load bearing strength was also measured for several wastes with solids content from 55 to 70 percent (Figure 15).[4] At 55 percent solids, the wastes can sustain virtually no load, while at 70 percent solids load bearing strength of 2.1 to 2.4×10^6 dyne/cm^2 (30 to 35 psi) exists for a Shawnee sludge. Levels capable of supporting a person while standing, 2×10^5 dyne/cm^2 (3 psi), by TVA Shawnee sludge would be attained at approximately 60 percent solids content.

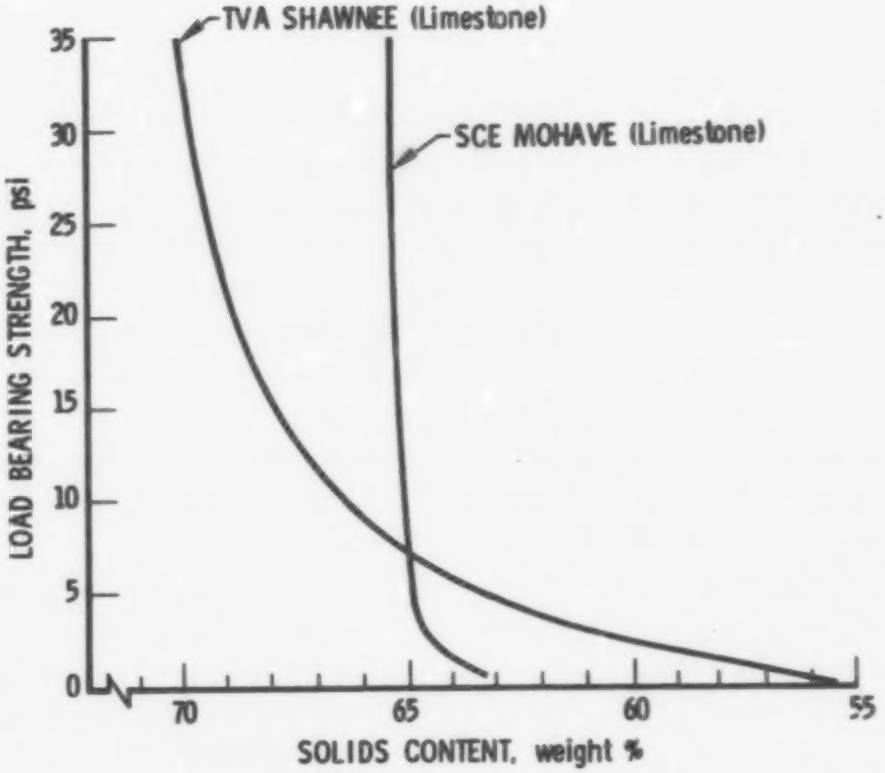


Figure 15. Load bearing capacity of FGC wastes

At 70 percent solids where the strength increased rapidly, the waste is at its saturation point. Removal of additional water reduces the lubrication between particles in the waste and accounts for the rapid increase in strength.

In the case cited above, accessibility to personnel could probably be permitted if the solids content is greater than 65 percent, at which point a load bearing capacity of 5.5×10^5 dyne/cm^2 (8 psi) is expected. It should be noted that this corresponds to the dryness expected by vacuum filtering (Figure 4).

With a solids content of 70 percent, vehicles could probably be supported safely. However, it should be noted that below 70 percent solids the strength drops rapidly. Mohave waste exhibited a sharp change in strength at 65 percent solids (Figure 15); for that material, load bearing strength ranged from about 2 to 20×10^5 dyne/cm^2 (3 to 30 psi).

Based on the dewatering results reported[5] solids content greather than 65 percent can be attained with the SCE Mohave wastes by using any of the dewatering processes--settling, centrifuging, or vacuum filtering. Consequently, if no free-standing water were present, a disposal site of Mohave waste could probably be traversed safely by personnel and equipment.

5.1.1.5 Disposal Methods

For disposal methods to be considered environmentally sound, they must provide the means of preventing or minimizing the seepage and flow of waste liquors into water supplies. Disposal methods may be grouped into one of two categories: (1) ponding and (2) landfilling. Each method has unique characteristics, and one or more may be applicable at a given site, depending on site conditions and the overall objectives of the user. These factors are evaluated in Reference 5 for a number of ponding and landfill alternatives for untreated and treated wastes.

Environmentally, each of the methods offers a different form of protection against water pollution, and a different approach to land reclamation. Since the long-term effects of ponding and landfilling are still being evaluated, no single method is considered superior to others for all cases, at this time.

5.1.1.5.1 Disposal Cost Estimates

Cost estimates for disposal in lined ponds and land-filling of chemically treated FGC wastes have been made and reported by Aerospace on several occasions. Detailed cost estimates were made of fixation disposal and were reported in Reference 13. The lined ponding cost estimates that were presented in Reference 4 were updated and are compared with fixation disposal costs in Table 10.

The estimates are based on a typical 1000-MW power plant burning coal with 3 percent sulfur and 12 percent ash. The service life of the power plant is assumed to be 30 years, with the plant operating at an average load factor of 50 percent, and with an annual average sludge (50 percent solids including ash) production of 930,000 metric tons (1,025,000 short tons). The annualized costs include the cost for labor, maintenance, and capital charges of 18 percent. The capital charges include replacements, insurance, taxes, cost of capital based on 50/50 debt/equity funding, and the use of straight-line depreciation.

This comparison indicates that the cost of ponding is approximately 75 percent of the fixation disposal costs. Additional costs for the reclamation of the site, which may include the addition of top soil and nutrients on fixed landfills, and a yet-to-be defined procedure for closing down an pond for permanent environmental protection are not included in the estimate. Excluded is any "cost reduction" in terms of realizing the residual value of the land where applicable; however, the land is depreciated throughout the lifetime of the pond. Any benefit realized from including current ash disposal with FGD total waste disposal where applicable is also excluded.

Table 10. DISPOSAL COST RANGES FOR PONDING AND CHEMICAL TREATMENT[a]

Disposal Method	\$/Ton of FGC[d, e] Waste (Dry)	\$/Ton of Coal[e]	Mills/kWh[e]
Lined Pond[b]	5.70 to 7.80	1.62 to 2.22	0.7 to 0.96
Chemical Treatment[c]	7.30 to 11.40	2.07 to 3.24	0.9 to 1.4

[a] 1000-MW station, 50% load factor, 30-yr average, January 1976 dollars (land costs at $1000/acre are included).

[b] Ponding costs cover range based on low-to-high material costs; i.e., PVC-20 (low) to Hypalon-30 (high).

[c] Fixation costs vary from low to high depending on characteristics of the waste and the disposal process chosen.

[d] 510,000 short tons/yr average (dry basis) including fly ash.

[e] Coal burned at rate of 0.88 lb/kWh (85% SO_2 removal: 1.2 $CaCO_3/SO_2$ mole ratio with an 85% SO_2 removal efficiency; 3% sulfur; 12% ash).

5.1.2 Shawnee FGD Waste Disposal Field Evaluation (TVA and The Aerospace Corporation)

This project, which is managed by the EPA Industrial Environmental Research Laboratory (IERL), Research Triangle Park, North Carolina, was initiated to evaluate and monitor the field-site disposal of untreated and treated FGC wastes. Its purpose is to determine the effects of several scrubbing operations, waste treatment methods, disposal techniques, soil interactions, and field operation procedures. Test samples of treated and untreated wastes, ground water, surface water, leachate, and soil cores are being analyzed in order to evaluate the environmental acceptability of current disposal technology. On the basis of this program, engineering estimates of total costs (capital and operating) projected for full-scale FGD waste treatment and disposal have been made.

Correlations are also being made between laboratory-prepared samples and those created under field operating conditions. The results obtained are being used to form a basic understanding of the characteristics of field operations, to define procedures for planning additional evaluation at this site, and to assist in the development of other EPA-sponsored field evaluations. The site selected for the evaluation was the TVA Shawnee Power Station at Paducah, Kentucky. Two 10-MW equivalent prototype flue gas scrubber systems, one using lime and the other limestone, produced wastes that were placed in five disposal ponds on the plant site. Two of the ponds contain untreated wastes; each of the remaining ponds contains wastes chemically treated by one to three commercial contractors.

The Aerospace Corporation is providing program planning and coordination and is conducting selected chemical analyses. Data evaluation, costing estimates, and reporting are also Aerospace responsibilities. TVA provides the on-site support relating to all pond construction and maintenance, filling of untreated ponds, and providing FGD waste for treatment. Sample collection, analysis and distribution to other organizations, climatological and hydraulic data collection, and photographic documentation services are also performed by TVA. Chemical treatment of the waste was performed by Chemfix, Inc., Pittsburgh, Pennsylvania; Dravo Corporation Pittsburgh, Pennsylvania; and IU Conversion Systems, Inc. (IUCS), Philadelphia, Pennyslvania. The Bechtel Corporation (the scrubber facility test director) provided the technical interface relating the scrubber test facility to the disposal evaluation.

The program began in September 1974 with the filling of the first untreated pond and is scheduled to continue through 1977. Reports on the first year's results have been published recently.[13-15] The highlights of the first year's findings are included herein. Future plans include the evaluation of other disposal conditions including gypsum disposal.

5.1.2.1 Project Status

The TVA Shawnee Power Station at Paducah, Kentucky, is the site of the field evaluation. Two different scrubber systems are being operated at this station as an EPA/TVA test facility. One scrubber is a Universal Oil Products (UOP) turbulent contact absorber (TCA) and uses limestone as the SO_2 absorbent; the other is a Chemico venturi followed by a spray tower using lime. Both scrub the fly ash and absorb the SO_2 as well. Each scrubber system is capable of independently treating up to 10 MW equivalent of flue gas from one boiler (approximately 30,000 ft^3/min at 300°F). Wastes from these scrubbers were used in the disposal evaluation and are undergoing analysis in several laboratories under EPA sponsorship.[13]

The disposal evaluation site consists of five disposal ponds, each occupying approximately 0.1 acre near the Shawnee plant, approximately one mile south of the Ohio River. All the ponds were filled between October 7, 1974 and April 23, 1975 to a depth of about 3 ft. The characteristics of the fill material are shown in Table 11. Two of the ponds contain untreated wastes; each of the remaining ponds contains wastes chemically treated by one of the three commercial contractors. The surfaces of

Table 11. POND AND FGC WASTE CHARACTERISTICS

Pond	Scrubber	Absorbent,	Untreated Solids Content, weight %	Fly Ash Solids Content, weight %	Treatment Contractor	Fill and Treatment Date
A	Venturi, spray tower	Lime, filter cake	46	43	Untreated	Sep 24 - Oct 8, 1974
B	TCA	Limestone, clarifier underflow	38	40	Dravo	Apr 7-15, 1975
C	Venturi, spray tower	Lime, centrifuge cake	55	45	IUCS	Mar 31 - Apr 23, 1975
D	TCA	Limestone, clarifier underflow	38 38	38 38	Untreated Untreated	Oct 11-20, 1974 Jan 13 - Feb 5, 1975
E	TCA	Limestone, clarifier underflow	38	38	Chemfix	Dec 3-7, 1974

the three treated ponds were sloped to create a wet section, consisting of a combination of liquor and rain water, and a potential dry section (depending on weather conditions) for the observation of physical conditions of dry material. Within each pond is a leachate well for sampling water that collects at the waste-soil interface. A ground water well is located on a bern of each pond, between the sludge and the river. Ground water wells are located approximately 100 ft south of each pond (away from the river) to provide for the monitoring of background water quality. The disposal sites are also being monitored periodically for leachate, supernate, and ground water quality, soil chemistry changes, and treated waste chemical and physical qualities.

Each of the three treated ponds was conditioned and filled by the respective contractors in response to program requirements so that various operational conditions and the effects of weather could be evaluated. These operations, therefore, were not representative of identical disposal conditions or necessarily the operational methods that would be employed by any of the contractors. For example, different input materials were supplied to the contractors, and the ponds were not provided with surface runoff drainage so that the effects of trapped water could be observed.

One treated material, from Chemfix, was fractured and contoured by a back hoe; another, from Dravo, represents curing and disposal under water where high strength is not necessarily required; and the other, from IUCS, was not compacted by placement vehicles that would be used in a full-scale operation. Therefore, comparisons between processes were neither attempted nor implied in the evaluations. The principal environmental effects being observed are the quality of seepage water and the strength and permeabilities of the treated materials. Correlations are also being made between laboratory-prepared samples and those created under field operating conditions. The results are being used to form a basic understanding of the characteristics of field operations.

5.1.2.2 Analytical Results

Considerable data have been reported from the analyses of input FGC wastes, supernate, leachate, ground water, and soil and treated material cores.[13] Since the quality of leachate and ground water and the strength and permeability of the fixed and raw wastes are some of the more significant of these data as they impact the environment, these results are summarized in Table 12. It is expected that these data will be expanded and correlated with other available laboratory and field evaluation data.

5.1.2.3 Untreated Wastes

The Pond A untreated waste leachate data show that the concentrations of the dissolved solids (Cl, SO_4, and TDS) progressively increase with time. The data also indicate that the concentrations of the constituents may approach those of the input liquor. Simultaneously, the concentrations of these same constituents in the pond supernate vary with time. Neither the scrubber system waste solids nor liquors are replenished; therefore, the supernate should become diluted with rainfall as the program progresses. Some fluctuation in this trend can be expected as a result of evaporation during dry periods. The detection of heavy metals in the leachate and supernate of this pond shows trends similar to the major species. However, concentration projections cannot be made at this time because of the relatively short period of time that the ponds have been extant. Continued monitoring is expected to clarify this situation.

The other untreated pond, D, was filled initially and used as the input source of material for the Chemfix operations at Pond E. At that time, approximately 75 percent of the waste from Pond D was removed and this pond was subsequently refilled with a similar waste several months later. Waste removal and refilling of this pond have produced leachate trend characteristics somewhat different from Pond A. Concentrations of the dissolved solids in the leachate are shown in Table 12 for this pond. The accumulation of additional data will continue throughout the program and is expected to produce trends that are characteristic of this material.

Table 12. POND LEACHATE ANALYSES

Pond	Absorbent	Fill Dates and Fixation Contractor	Input Waste Liquor		Weeks after Filling	SO$_4$, ppm^b	Cl. ppm^b	TDS, ppm^b
			Solids, wt%	TDS, ppm				
A	Lime	October 1974, untreated	46	8285	1	700	600	2200
					30	1250	3300	7500
					55	1250	3400	7560
D	Limestone	October 1974 and February 1975, untreated	38	5445	1[a]	590	210	1300
					9	580	-	5200
					19	1420	1300	4000
					56	1750	500	3370
B	Limestone	April 1975, Dravo	38	5685	2	530	460	1800
					11	490	940	2600
					27	675	1100	2670
C	Lime	April 1975, IUCS	55	9530	1	50	2400	4700
					11	190	1200	3200
					19	820	1100	3300
E	Limestone	December 1974, Chemfix	38	6245	9	300	1000	2400
					20	670	-	3400
					30	800	740	3200
					47	900	490	2690

[a] Weeks from first filling.

[b] Surface water in leachate wells at Ponds A, B, D, and E resulted in a dilution of the early leachate samples.

Analyses of samples of ground water (approximately 12 ft below Pond A and 40 ft below Pond D) have not shown any effect of seepage from these ponds.

5.1.2.4 Treated Wastes

The data from the ponds containing treated wastes, although sampled over a shorter period of time, show trends similar to those of the untreated waste except that the reduced concentrations of the constituents are evident in the leachate from the chemically fixed wastes. Indications are that these concentrations either start at or quickly build up (depending on the amount of rain water initially present in the leachate well) to approximately 50 percent of the respective concentrations in the liquor of the untreated input waste (Table 12). Sampling is conducted bimonthly; data illustrative of the trends are presented in Table 12. The long-term results of these field evaluations will be evaluated and reported throughout this project.

Laboratory column tests were conducted on an untreated TVA Shawnee limestone scrubbing waste and a core taken from a treated pond at the Shawnee disposal site. Chemical analyses of the leachate were performed to define long-term TDS concentration trends; the results are shown in Figure 16. The treated material contained limestone scrubber waste; of the three treated ponds, the oldest one has been in operation for approximately one year. In these analyses, distilled water was allowed to seep through the pores of the samples, and chemical analyses of the collected leachate were made periodically. Figure 16 shows the TDS concentration as a function of pore volume displacement of leachate water (pore volume being defined as the nonsolid volumetric portion of a given mass). These trends are generally typical for the various constituents of the materials, including trace elements.[13,14]

Several significant characteristics are shown in the data presented in Figure 16. Both treated and untreated wastes display a steep drop in leachate TDS concentration during the first five pore volume displacements. During this period, salts from the sludge liquor trapped within

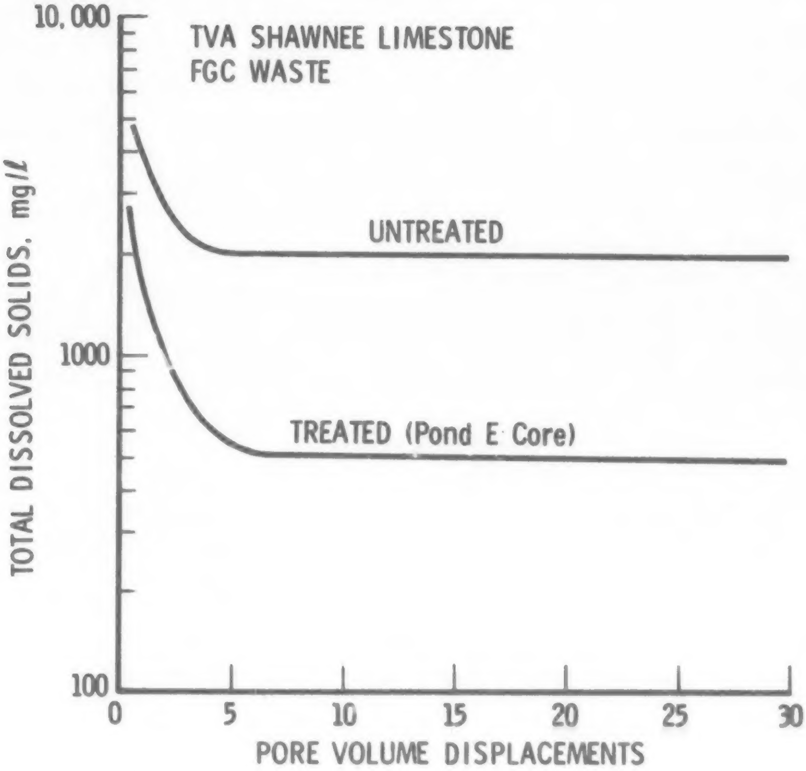


Figure 16. Results of laboratory column leaching tests of treated and untreated wastes

the pores are flushed out. Thereafter, solubility of the sulfite, sulfate, and chloride within the solid mass becomes a controlling factor. Another point of interest is that the time to achieve five pore volume displacements is not the same for the two materials. Because the permeability rate of the treated material is at least one order of magnitude lower than the untreated material, the seepage of five pore volumes through the treated waste is significantly delayed relative to the seepage through untreated wastes. A third significant point is that, after the initial flushing period, the leachate and the TDS concentrations stabilized at about 1900 ppm for the untreated and 500 ppm for the treated. This represents a reduction in TDS concentration of the leachate from treated material to about 25 percent of the untreated waste.

The combined effects of all these factors are shown in Figure 17 for the five cases defined in Table 13. These initial results are from an analysis being conducted to project data (as in Figure 16) on operational conditions and time periods well beyond the end of this particular project. Because a treated disposal site releases leachate to the subsoil over a longer time period and at smaller concentrations than an untreated disposal site, this analysis compares the treated and untreated materials in terms of the mass per unit area of dissolved solids released to the subsoil as a function of time.

The advantages of reducing the permeability and the solubility of the wastes and of preventing water from accumulating on the surface are highlighted in Figure 17. For example, for the first 100 years, a treated material in a landfill with controlled runoff (Case 5) releases approximately 1/80 of the mass of dissolved solids at a given rate to the subsoil as an untreated material in a lake (Case 1), and approximately 1/10 as much as an untreated material in a pond (Case 3). The time in years to reach five pore volume displacements (initial drainage period) is also shown.

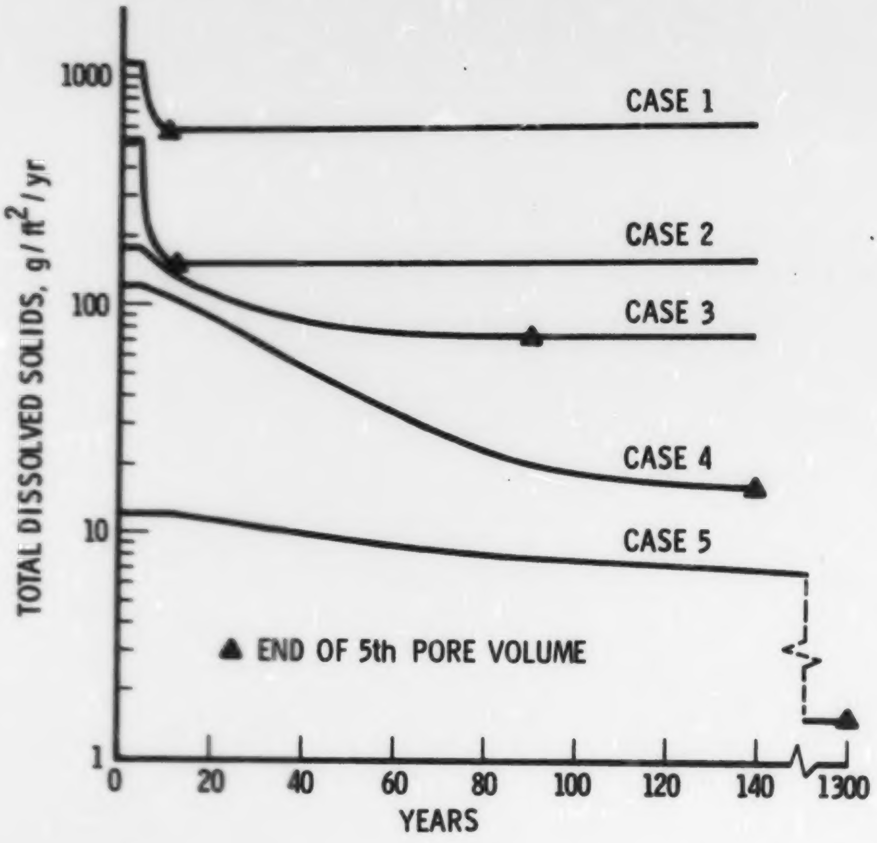


Figure 17. Mass loading of TDS to subsoil for various disposal modes of treated and untreated FGC wastes

Table 13. CASES STUDIED FOR CALCULATING MASS LOADING OF LEACHATE CONSTITUENTS INTO SUBSOIL

Case	Disposal Method	Surface Water	FGC Waste, 5-Year Fill			
			Waste Condition	Depth, ft	Permeability, cm/sec[b]	Fractional Pore Volume
1	Lake[a]	Constant supernate	Untreated	30	10^{-4}	0.67
2	Lake[a]	Constant supernate	Treated	30	10^{-5}	0.67
3	Pond	10. in./yr recharge	Untreated	30	10^{-4}	0.67
4	Pond	10. in./yr recharge	Treated	30	10^{-5}	0.67
5	Landfill	1 in./yr recharge	Treated	30	10^{-5}	0.67

[a] Assumed maximum hydraulic head of 6 ft during filling, including depth of wastes; 1 ft constant water cover thereafter.

[b] For all cases, subsoil permeability = 10^{-5} cm/sec.

Such analyses are being continued; more specific operational parameters will be applied as they evolve. Although some methods of disposal release much lower mass to the subsoil than others, it is not apparent at this time that the methods with the lower release rates are the only acceptable approaches. Criteria for judging disposal methods are being determined by the EPA and will be applied when they are available.

Some preliminary physical properties of the fixed wastes are given in Table 14. Of particular interest are the permeabilities in the range of 6.9×10^{-5} to 5.5×10^{-7} cm/sec and unconfined compressive strengths of 3 to 39 ton/ft^2. Additional measurements of these properties will be made on material from corings from the treated ponds taken periodically throughout this project. FGC wastes that have not been treated or conditioned have permeability coefficients of approximately 10^{-4} cm/sec. The structural strength is of no practical consequence. The effects of conditioning untreated wastes, e.g., dewatering and compaction, are being studied.

5.1.2.5 Soil

The ground waters show no evidence of altered quality resulting from the filling of any of the five ponds. This result is in agreement with expectations based upon the low permeabilities of clay soil samples from the floor of the ponds. Based on soil characteristics, permeability coefficients in the range of 10^{-8} cm/sec have been defined by TVA. Thus, in one year, the waste leachate constituents would be expected to permeate to a depth of less than 0.5 in. Laboratory analyses using an ion microprobe mass analyzer are under way to detect the progress of the constituents in successive soil cores in order to verify long-range analytical predictions over the relatively short time period available within the time span of the evaluation program. At this point, the initial calibration runs have been completed on pond floor core samples to provide background data for future tests.

Table 14. CHARACTERISTICS OF CORES FROM CHEMICALLY TREATED FGC WASTES

Sample Source and Date	Unconfined Compressive Strength, psi		Density, g/cm^3		Water Content, wt%	Estimated Fractional Pore Volume	Water Permeability, cm/sec
	Wet[a]	Dry[b]	Wet[a]	Dry[b]			
Pond E[c] 2/27/75	103 to 133	95 to 165	1.40 to 1.46	0.69 to 0.73	51.0 to 51.5	0.71 to 0.73	1.5 to 2.7×10^{-5}
Pond B[d] 6/12/75	27 to 33	40 to 46	1.36 to 1.44	0.59 to 0.62	56.9 to 57.8	0.75 to 0.76	6.9×10^{-5}
Pond C[c] 5/29/75 6/12/75	410 to 510	470 to 540	1.67 to 1.70	1.05 to 1.08	36.5 to 37.0	0.57 to 0.58	5.5×10^{-5} 5.5×10^{-7}

[a] Wet: as received.

[b] Dry: after oven drying.

[c] Samples from Ponds E and C were taken from locations free of surface water.

[d] Pond B material was kept underwater continuously as in the case of disposal upstream of a dam.

5.1.2.6 Future Plans

Plans are being developed to expand the TVA Shawnee site evaluation to add two impoundments in order to evaluate other disposal methods for untreated FGC wastes. The two wastes being considered are (1) an oxidized sulfite waste and (2) a dewatered limestone waste that does not contain fly ash, but to which is added a low-solids-content fly ash, mixed and compacted at the test site.

These sites should be operating by the summer of 1976. Later in this project, one or two of the four untreated disposal areas will be drained of water and allowed to air-dry. The sites will then be capped, contoured to drain rainwater, planted, and monitored for leachate quantity and characteristics, as well as the strength of the material, throughout the remainder of the project.

5.1.3 Laboratory and Field Evaluation of FGC Waste Treatment Processes (U.S. Army Engineer WES)

Studies are being conducted by the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, Mississippi, to evaluate chemical treatment (fixation) and environmental effects associated with the disposal of FGC wastes. The program also includes a number of industrial wastes. Although the industrial wastes will not be specifically addressed in this report, the evaluation of the pollutant potential of these wastes will be similar to those originating in the FGC processes.

The program has been divided into three areas encompassing the following tasks:

a. Assessment of the pollution potential of the leaching of untreated and chemically fixed FGC wastes.

b. Site survey and environmental assessment of existing solid waste disposal sites.

c. Evaluation of existing FGC waste fixation technology.

In assessing the pollution potential of the wastes, five chemical fixation processes were used to threat five FGC wastes (Table 15). The processes are being evaluated by means of leaching column studies and physical and chemical testing of untreated and fixed wastes.

This task was initiated in July 1974. Interim reports will present the results of physical properties of untreated and treated wastes and the column results from leaching untreated wastes after approximately eight months and treated wastes after about four months. The leaching experiments are planned to continue for a total of two years. A summary of the analyses and tests being conducted will be provided later in this report.

In order to accelerate the acquisition of a data base to assess the pollutant migration and environmental impact from FGC wastes on land disposal sites, a task to survey and characterize existing disposal sites has been initiated. The primary goal will be to establish the extent of pollutant migration from existing disposal sites, the relationship to site history and disposal operations, and the establishment of site selection criteria. The geology, hydrology, and chemistry of the sites and their surrounding media will be studied. In addition to FGC disposal sites, industrial waste and municipal refuse sites are included in the program. This report, however, will emphasize the FGC aspects. Work on this task was begun in July 1975 and is expected to continue for two years.

The third task portion of the study involves the evaluation of existing fixation technology. It is planned to compile a list of fixation processors currently available and identify their respective areas of application. Another objective is the development of a methodology for selection and application of fixation technology based on economic analysis and process evaluation. The latter includes the definition and development of a screening test for rapid and accurate assessment of the potential environmental impact associated with the fixation and disposal of FGC wastes. The program is currently being initiated and is expected to extend over a two-year period.

Table 15. FGC WASTE AND CHEMICAL TREATMENT MATRIX

Code No.	Type of FGC Waste	Process Code Letter[a]				
		A	B	E	F	G
100	Lime process, eastern coal	X	X	X	X	X
400	Limestone process, eastern coal	X	X	X	NA	X
500	Double-alkali process, eastern coal	X	X	X	NA	X
600	Limestone process, western coal	X	X	X	X	X
1000	Double-alkali process, western coal	X	X	X	NA	X

[a] X: Waste fixed by processor and being tested in column
NA: Not applicable
Processes A, B, E, F, and G include (not listed in alphabetic order):

- Cement and fly ash additive
- Proprietary additive will pH adjustment
- Cement and sodium silicate additive
- Proprietary additive with pH adjustment
- Fly ash and lime additive

The physical and engineering properties being reported are outlined in Table 16. Bulk density, porosity, permeability, and unconfined compressive strength data were reported in Reference 12 and are summarized in Table 17. Fixation of the FGC waste results in a consolidated material which is generally of higher density than the untreated waste, has lower porosity and permeability and which demonstrates a degree of structural strength.

5.1.3.1 Assessment of Pollution Potential of Leaching of Untreated and Chemically Fixed FGC Wastes

This task was initiated in July 1974. Five chemical fixation processes were used to treat five FGC wastes (Table 15). The processes will be evaluated by means of leaching and physical and chemical testing of the untreated and chemically fixed wastes. The principal objectives of this task are as follows:

a. To assess the application of fixation technology for retarding the leaching (mass transport) of pollutants from selected FGC wastes

b. To assess the leaching potential of those wastes

c. To determine the physical stability of the fixed wastes and its relationship to disposal operations

d. To evaluate the potential role of fixation of FGC wastes as a pretreatment process prior to ultimate disposal

5.1.3.1.1 Physical Testing

Physical testing of the raw and fixed wastes has been completed, and a report is being published.[16] The approach taken by WES was to characterize the wastes by evaluation of their physical and engineering properties as determined by standard tests and procedures applied to soils.

The effects of the fixation process can then be assessed by evaluating the change in properties resulting from fixation. Additional characterization is possible by comparison of results with typical values of familiar materials such as soil-cement, concrete, and soils.

Table 16. PHYSICAL AND ENGINEERING PROPERTIES

Physical Properties
Specific Gravity
Bulk Density
Dry Density
Water Content
Void Ratio
Permeability
Grain Size Distribution
Engineering Properties
Compaction Test
Maximum Dry Density Optimum Moisture Content
Unconfined Compression Test
Undrained Compression Test Unconfined Compressive Strength Modulus of Elasticity
Wet-Dry Weight Loss
Freeze-Thaw Characteristics

Table 17. PHYSICAL PROPERTIES OF UNTREATED AND TREATED FGD WASTES

Sample Identification No.	Dry Bulk Density, lb/cf	Porosity, %	Permeability, cm/sec	Unconfined Compressive Strength, psi
R-100	51.7	67.3	1.07×10^{-5}	-
R-400	63.1	64.2	7.78×10^{-5}	-
R-500	52.3	74.0	2.50×10^{-5}	-
R-600	89.0	48.5	1.44×10^{-5}	-
R-1000	47.4	75.4	6.54×10^{-5}	-
A-100	100.1	51.4	2.06×10^{-6}	100.3
A-400	108.3	55.6	-	-
A-500	95.5	57.8	1.13×10^{-7}	188.3
A-600	109.3	41.0	4.31×10^{-7}	403.1
A-1000	96.6	51.4	8.95×10^{-7}	337.4
B-100	77.0	75.3	1.59×10^{-4}	23.7
B-400	89.0	75.5	1.08×10^{-5}	44.5
B-500	90.8	71.6	4.56×10^{-5}	42.7
B-600	79.6	76.3	3.96×10^{-5}	35.3
B-1000	81.5	73.2	6.62×10^{-5}	23.2
E-100	101.1	45.7	7.94×10^{-4}	2570.0
E-400	82.7	55.4	2.52×10^{-6}	720.0
E-500	99.3	49.0	4.54×10^{-11}	2220.0
E-600	110.9	35.4	3.57×10^{-8}	4486.0
E-1000	82.7	50.8	7.33×10^{-7}	1374.0
F-100	-	-	-	-
F-600	81.0	52.4	5.01×10^{-6}	395.6
G-100	-	-	-	-
G-400	62.7	69.7	5.24×10^{-5}	242.6
G-500	52.5	75.4	1.39×10^{-4}	86.4
G-600	56.9	73.4	1.22×10^{-4}	126.1
G-1000	68.1	70.0	4.05×10^{-5}	144.3

5.1.3.1.2 Leaching Tests

The leaching tests are aimed at measuring the rate of pollutant migration into an aqueous medium. One hundred sixty-two columns have been assembled to simulate the dispersed flow and leaching of pollutants at surfaces of cracks within the treated waste matrix. For treated wastes a leaching surface-to-sludge volume ratio of 1.0 to 1.5 is being tested. A treated sludge core, 3 in. in diameter and with a volume of approximately 0.35 in. has been placed within a 4-in. (inner diameter) column, and the annular space has been filled with polypropylene pellets. The leachate flow rate is controlled to maintain a fluid velocity of about 1×10^{-5} cm/sec. Two leaching fluids are being used to represent both sides of the pH spectrum and to provide some insight into the effect of pH on leaching. One fluid is water saturated with carbon dioxide having a pH of 4.5 to 5.0, and the other is deionized water buffered with boric acid and a pH of 7.5 to 8.0. The columns are being triplicated for each leaching solution.

Interim results of the leaching column studies are expected to be available shortly.[16] Data on untreated wastes that have been leached in columns for approximately eight months and treated sludge exposed for about four months are expected. In some cases, trends have not been established, and additional data are required before comparisons can be drawn. A listing of the data being acquired is reported in Table 18.

Information excerpted from a forthcoming WES report was published in Reference 12; representative results are reported herein. Specific conductance has been reported as a measure of the total TDS present in a solution. The results presented in Figure 18 are paired data for conductivity and dissolved solids on elutriates from all untreated and fixed sludges utilized in the WES study. The data demonstrate a strong linear relationship between these parameters and may be used to interpret conductivity data derived from the leaching experiments by inferring a relationship to dissolved solids.

Table 18. CHEMICAL CHARACTERISTICS TESTS OF UNTREATED AND TREATED FGC WASTES

<table>
<tr><th colspan="3">Chemical Analysis: Concentration as a Function of Time</th></tr>
<tr><th>Cations</th><th>Anions</th><th>Organic</th></tr>
<tr><td>Arsenic</td><td>Chloride</td><td>Chemical oxygen demand</td></tr>
<tr><td>Beryllium</td><td>Cyanide</td><td>Total organic carbon</td></tr>
<tr><td>Cadmium</td><td>Fluoride</td><td></td></tr>
<tr><td>Calcium</td><td>Nitrate</td><td></td></tr>
<tr><td>Chromium</td><td>Nitrate</td><td></td></tr>
<tr><td>Copper</td><td>Sulfate</td><td></td></tr>
<tr><td>Lead</td><td>Sulfite</td><td></td></tr>
<tr><td>Magnesium</td><td></td><td></td></tr>
<tr><td>Manganese</td><td></td><td></td></tr>
<tr><td>Mercury</td><td></td><td></td></tr>
<tr><td>Nickel</td><td></td><td></td></tr>
<tr><td>Selenium</td><td></td><td></td></tr>
<tr><td>Zinc</td><td></td><td></td></tr>
<tr><td colspan="3">Leachate pH</td></tr>
<tr><td colspan="3">Leachate Electrical Conductivity, µmhos/cm</td></tr>
</table>

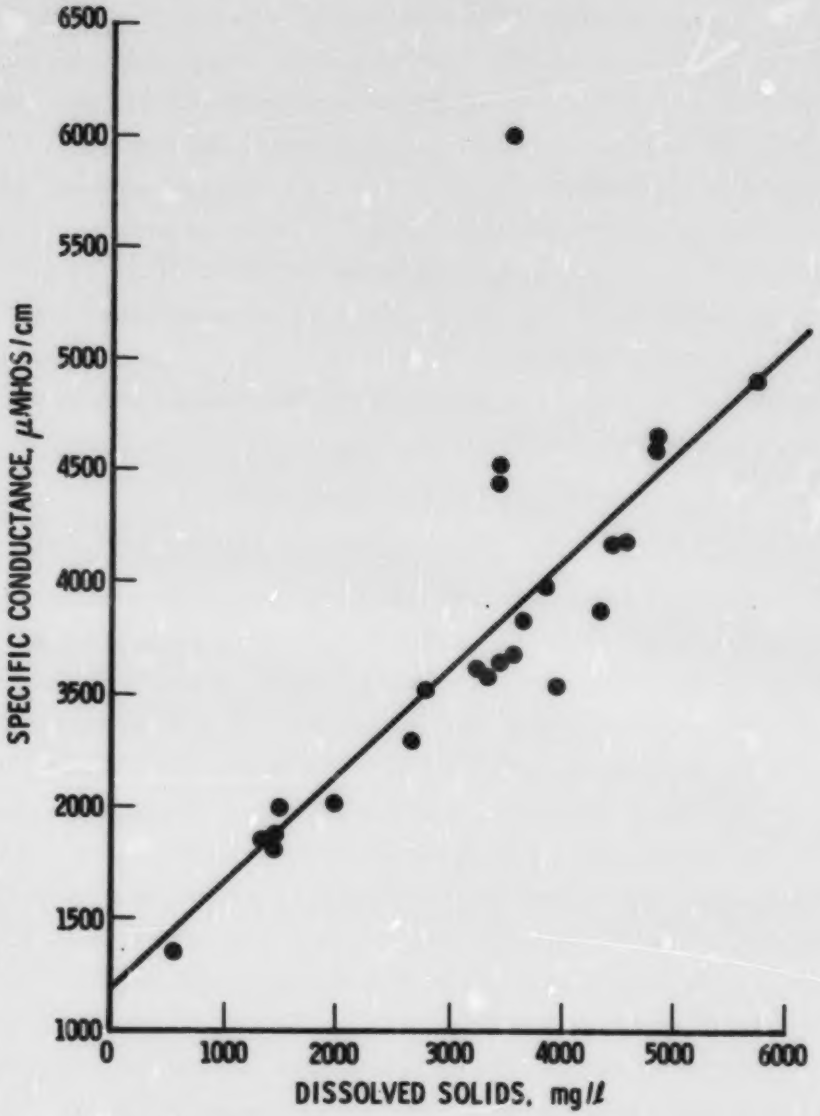


Figure 18. Conductivity versus dissolved solids

For the experiments being conducted, the effect of the process on leachate characteristics is illustrated in Figures 19 and 20 for treated and untreated double-alkali and lime sludges. Generally, the concentration of sulfate in the leachate from the treated material is lower than that from untreated. However, this is not always the case, e.g., where process G appears to be typically higher and others exhibit a varying degree of reduction in sulfite from slight to several orders of magnitude.

At this time, any conclusions based on these data are premature, inasmuch as the results reporting characteristics of other constituents will not be available until the WES interim report[16] is published. Also, the long-range effects cannot be assessed as the results represent approximately only six to eight months of leaching data.

5.1.3.2 Site Survey and Environmental Assessment of Existing Solid Waste Disposal Sites

Site investigation is divided into preliminary investigative, sampling, analysis, and environmental assessment. It is expected that candidate site characteristics related to history, waste characteristics, geology, and hydrology will be defined and quantified. A total of five sites will be selected. A boring and sampling program will also be defined. Samples of the waste, soil, pore water, and groundwater will be taken and analyzed for chemical constituents and partition of pollutants (Table 19). The present investigation is confined to a laboratory leaching test to assess the mobility of pollutants under selected conditions. It is expected that these results will give an insight into the mechanisms for pollutant transport from residues outside the boundary of a disposal area. Physical properties will also be determined. From these data, a preliminary assessment of the environmental impact of land disposal for residues may be stated, but an exact characterization of the degree of environmental impact, if any, will have to await further investigations.

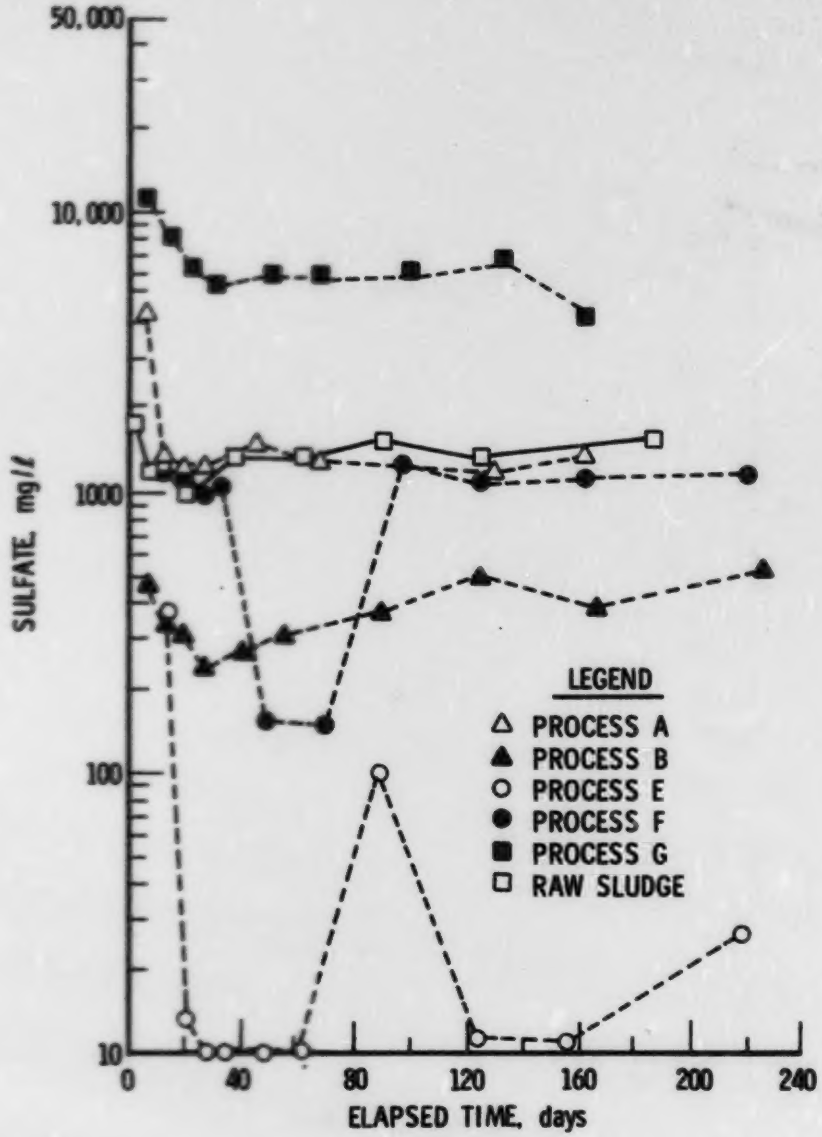


Figure 19. Leaching results: sulfate, sludge No. 100

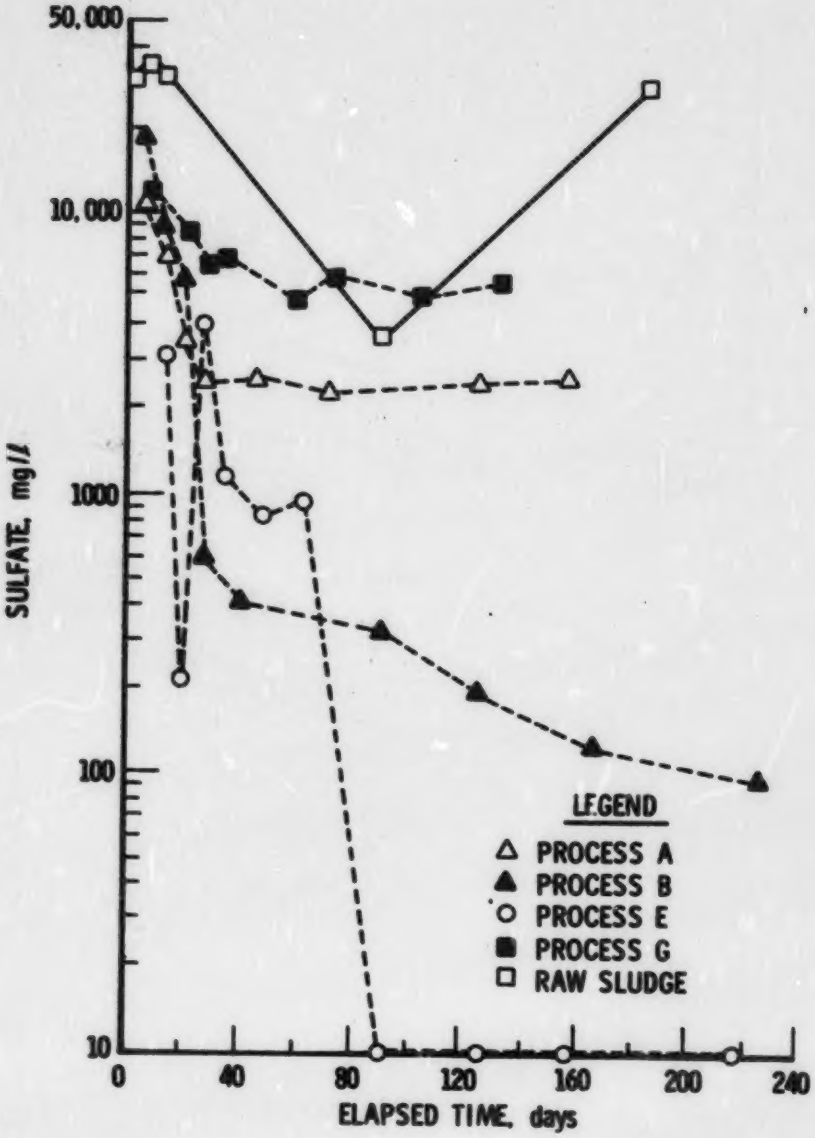


Figure 20. Leaching results: sulfate, sludge No. 500

Table 19. CHEMICAL ANALYSES ON SAMPLES FOR SITE SURVEYS

Arsenic
Beryllium
Cadmium
Chromium
Cyanide
Copper
Mercury
Magnesium
Manganese
Nickel
Iron
Lead
Selenium
Zinc
Sulfite
Sulfate
Boron
Chloride
Vanadium
Nitrites
Nitrate
Hydrocarbons
Total organic carbon

To date, contact has been made with all companies known to have operational FGD sludge disposal sites. One site has been visited and rejected for study because of geologic conditions at the disposal site.

5.1.3.3 Evaluation of Existing FGC Waste Fixation Technology

During this portion of the study, a compilation of FGC waste processes currently available will be made and their respective areas of application identified. The development of a methodology for selection and application of fixation technology based on economic analyses and process evaluation is also planned. The latter task includes the definition and development of a screening test for rapid and accurate assessment of the potential environmental impact associated with the fixation and disposal of FGC wastes. The program is currently being initiated and is expected to extend over a two-year period. The same FGC wastes that were evaluated in the pollution potential task (Table 15) will be treated with a number of materials selected on the basis of a survey of the Corps of Engineers soil and dust control materials and methods. On the basis of field experience by the Corps of Engineers, a list of candidate materials has been identified (Table 20). Limited testing, appropriate to define optimum concentration of additives, will be performed. The screening criteria which are being defined will be developed to evaluate the efficacy of potential fixation processes and also the environmental effects of solid waste on a disposal site.

5.1.4 Characterization of Effluents from Coal-Fired Power Plants (TVA)

This interagency-funded program with TVA is being conducted by the Power Research Staff, Chattanooga, Tennessee: Studies of liquid- and solid-related effluents are under the cognizance of Julian W. Jones, the

Table 20. LIST OF CANDIDATE FIXATION MATERIALS

Cement

Lime

Calcium Carbide

Sodium Silicate

Chrome Lignin

Analine Furfural

A Polyurethane Resin

A Water-Soluble Acrylamide and Diacrylamide

An Unsaturated Polyester Resin

A Dialkyl Dimethl Ammonium Chloride

Three Proprietary Compounds That Solidify by a Hydration Reaction

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EPA Industrial Environmental Research Laboratory (IERL), Research Triangle Park, North Carolina; studies of gaseous effluents are under Ron A. Venezia, also of IERL. This report addresses the work in the liquid- and solid-waste areas only.

The water- and solid-waste program is comprised of 5 tasks extending over a period of approximately 38 months. A final report is planned for late 1978. Chemical properties of coal-pile drainage will be characterized and quantified. A second task will be an assessment of the adjustment of pH on the physical and chemical composition of ash pond effluents for purposes of meeting effluent standards. The frequency of sampling and analysis for an effective ash pond monitoring program will be defined, and a monitoring system designed and tested. The effects of coal ash leachate on ground water quality will be characterized and quantified; lastly, an assessment of the total residual chlorine, its components (free and combined), and chlorinated organics discharged from a once-through cooling system will be conducted. The status of the various tasks as of December 31, 1975 is shown in Table 21.

5.1.5 Fly Ash Characterization and Disposal (TVA)

The objectives of this interagency-funded program with TVA, Power Research Staff, Chattanooga, are to characterize chemically and physically, coal-fired boiler ashes and their waste effluents. In addition, studies on fly ash handling systems and disposal, utilization, and treatment methods for water reuse will be conducted. Work was initiated in June 1975, and the final report on the project is planned for December 1979. Specifically, data from TVA and other sources on the characteristics of ash will be summarized and evaluated. Secondly, chemical and physical analyses of coal, coal ashes, and ash effluents are planned in order to characterize these materials at two different plants with different boiler designs and burning different types of coal. The various methods available for disposal and utilization of fly ash may also be evaluated, depending on fuel availability.

Table 21. PROGRAM STATUS

Program	Remarks
Characterization of Coal-Pile Drainage	The Colbert and Kingston plants were selected for the study. The definition of the experimental and sampling program has been completed for Kingston and is under way at Colbert.
Assessment of pH Adjustment	A mathematical model and computer program have been developed to simulate the batch settling characteristics of fly ash and bottom ash in a continuous pond system. A preliminary field study was completed for the Colbert plant with samples taken for chemical analysis. Laboratory column studies are being conducted.
Design of Monitoring System for Ash Pond Effluents	Analysis of effluent data is still under way. Recently available information is being incorporated into the analysis to develop the experimental design. The Kingston and Colbert plants were selected as the sites for sample collection and evaluation.
Effect of Coal Ash Leachate on Water Quality	The Kingston and Colbert generating plants were selected as the site for this investigation. Soil core samples and monitoring wells will be installed. A one-year sampling program is planned. Because of geological complications at Colbert, the Widow's Creek plant has been tentatively selected as a replacement.

(Continued)

Table 21. PROGRAM STATUS (Continued)

Program	Remarks
Effect of Chlorinated Effluents	The Kingston plant was selected for study. However, preliminary studies indicated that the intake water pH was high and varied seasonally. Because of these widely varying conditions, further testing was dropped, and the John Sevier plant was selected as a possible site for future work. Evaluation of preliminary data, water quality, and chlorine demand is being performed.

The first phase of the program, scheduled for completion in June 1978, will conclude with a summary of information on methods of treating sluice water for reuse.

Studies of dry and wet ash handling systems may be conducted, and recommendations may be made relative to the more promising systems for ash handling, disposal, and utilization alternatives.

The TVA plants at Colbert and Kingston have been selected for conducting chemical analyses of the streams. Complete stream characterization will be conducted initially for the Colbert plant only. It is to be noted that some of the work is being performed under another project, "Characterization of Effluents from Coal-Fired Power Plants," reported in Section 5.1.4.

In order to develop sampling procedures and methods, a preliminary sampling program was conducted at the Colbert Steam Plant. Sampling sites included the coal scales, pulverizers, mechanical collector, electrostatic precipitator (ESP), and pyrite hoppers and their respective ash slurry streams. Some sampling problems were experienced. These were primarily associated with various outages of plant equipment. Modifications in procedures as a result of the preliminary sampling program are being devised. The summary of coal and ash data is expected to be completed in calendar year 1976. Other tasks are in initial stages of implementation.

5.1.6 Studies of Attenuation of FGC Waste Leachate by Soil (U.S. Army Materiel Command)

The U.S. Army Materiel Command, Dugway Proving Ground, Utah, is conducting a study to determine the extent that heavy metals and other chemical constituents of FGC wastes can migrate through soil in land disposal sites. The experimental FGC program was initiated in December 1975 and will be conducted over a period of 24 months. The project consists of the following tasks: (1) physical and chemical characterization of wastes and preliminary screening tests with a variety of United States soil types, (2) leachate studies in columns with the wastes applied to two selected (best and worst) soil types, (3) long-term permeability tests with selected clays, and (4) interpretation of data from the tests in (1) and (2) to identify soil attenuation mechanisms and to develop empirical attenuation coefficients for specific chemical substances.

Six FGC wastes, as well as fly ash from one source, will be leached with water through six clay-type soils. The sources for the wastes and soils have been selected and are summarized in Table 22. The columns are transparent, 2 in. in diameter, and will be operated in groups of three. A head of 8 ft of liquid will be maintained over a 4-in. sludge and soil sample.

In addition to sampling and analyzing the leachate from the columns for heavy metals and other chemical constituents that may impair water quality, provisions have been made to obtain leachate samples at the waste-soil interface of the columns. This leachate will also be analyzed. When one of the compounds is found in the soil column effluent ("breakthrough"), one of the three columns will be sectioned, digested, or extracted, and each section will be analyzed for the compounds of interest. This will provide information as to the distribution and mobility of the compounds through the soil with time. The remaining two columns will continue to be leached until one or two additional compounds are detected (this will be somewhat dependent upon the time between the first and second breakthrough). One of the two remaining columns will then be sectioned and analyzed as previously described. The remaining column will be treated with a fresh portion of waste, and the leaching will be continued until a significant change is observed in the concentration or the composition of the soil column effluent (pH, conductivity, or concentration of metals breaking through the column).

Flow rates through the column will be monitored in order to detect any changes in permeability of the soil resulting from possible interactions with the wastes. Flow rate tests through the soil in the columns are currently being conducted. Although uniform procedures and techniques are used to pack the soil into columns, a wide range of flow rates may be observed through the column when conditions have equilibrated after several

Table 22. SOURCES OF FGC WASTES AND SOILS IN THE SOIL ATTENUATION TEST PROGRAM

FGC WASTES

Sources	Type of Material
Duquesne Light Co., Phillips Power Station	Wet lime-scrubbed flue gas waste including fly ash; eastern coal
Commonwealth Edison Co., Will County Station	Wet limestone-scrubbed flue gas waste including fly ash; eastern coal
GM, Parma	Double-alkali process waste; eastern coal
Arizona Public Service Co., Cholla Station	Wet limestone-scrubbed flue gas waste including fly ash; western coal
TVA Shawnee	a. Wet lime- and limestone-scrubbed flue gas waste including fly ash; eastern coal b. Fly ash; eastern coal
Kansas City Power and Light and Kansas Gas and Electric, LaCygne Station	Wet limestone-scrubbed flue gas waste including fly ash; eastern coal

Soils[a]

Source	Soil Order and Great Soil Group
Davidson, NC	Ultisol; R B Lateritic
Chalmers, IN	Mollisol; Prairie
Nicholson, KY	Alfisol; G B Podzolic
Shawnee, KY	
Dugway, UT	

[a] All soils are clay-type.

days of flowing. A number of columns (approximately twice the number required) are being packed and flow-tested to obtain columns with similar flow characteristics.

Soil characterization tests, i.e., pH, cation, exchange capacity, and mineralogy, are being performed and will be compared to the column results to determine if these tests may be used as a predictive technique in screening and assessing suitability of soils in any disposal site.

FGC wastes from two sources are being tested in this program, from the Phillips station and Will County. Material from the two locations are also being used in the leachate liner compatibility studies conducted at WES (Section 5.2.2).

5.1.7 Establishment of a Data Base for FGC Waste Disposal Standards Development (SCS Engineers)

A program was initiated in December 1975 with SCS Engineers, Long Beach, California, to establish a data base for use by EPA in its development of FGC waste disposal standards. Preceding the development of such a data base, an evaluation will be performed of the potential technological and economic impacts of applying any existing standards or regulations.

The criteria that may be considered in the development of standards or regulations when evaluating land disposal options will be defined. Health, ecological, and aesthetic factors based on FGC waste characteristics and land site considerations will be included. In addition, a compilation of any proposed or existing standards and regulations applicable to land disposal of FGC wastes is planned. The technological and economic impact of options available for complying with such standards and regulations and the economic and institutional impacts of their application will be assessed.

Subsequently, a technical data base for standards development will be established. This involves a definition of the interrelationships between environmental effects (health, ecological, safety, and aesthetics) and regulatory approaches (local, regional, and national) subcategorized by FGC waste characteristics, control, and treatment technology. Recommendations will be made for research and development needs and priorities needed to implement any potential standards or regulations.

5.2 PROCESS TECHNOLOGY ASSESSMENT AND NEW TECHNOLOGY DEVELOPMENT

The technology assessment and development efforts, totaling four projects, include (1) field studies of untreated and chemically treated FGC wastes, (2) FGC waste leachate-disposal site liner compatibility studies, (3) studies to correlate waste solid characteristics with scrubber operating conditions, and (4) dewatering equipment design studies.

5.2.1 Evaluation of FGD Waste Disposal Options (Louisville Gas and Electric)

Studies including the chemical and nonchemical processes for the stabilization of FGC scrubber wastes are planned in this 18-month project with Louisville Gas and Electric Company, Louisville, Kentucky. Laboratory testing and field evaluations of stabilized wastes are included. The contract is currently being negotiated and is expected to begin in the second quarter of CY 1976. The test program is expected to be conducted by Combustion Engineering, Windsor Locks, Connecticut.

Laboratory-scale tests will be conducted to determine optimum conditions for chemical treatment and physical stabilization of carbide lime and commercial lime FGC scrubber wastes. The scrubber wastes will be treated with lime, slaked lime, and portland cement additives. Some of these formulations will contain fly ash, and others will not. Chemical and physical screening tests will be performed on the samples comprising a matrix of treatment conditions. Selection will be made of the treated mixtures and processing conditions that will receive further evaluation under field conditions.

The field studies will include 25 yd^3 (19 m^3) above-ground impoundments of the treated wastes. Leachate, runoff, and physical property tests of stabilized and unstabilized wastes are planned. Two stabilized wastes will be selected for evaluation in 100 yd^3 (76 m^3) landfills. As in the smaller scale impoundment studies, leachate, runoff, and physical properties of the wastes will be determined.

An interim report is planned upon completion of the laboratory studies, approximately eight months after start of the program. Field tests are scheduled to begin approximately five months after go-ahead and continue for approximately one year thereafter. A final report will be issued on conclusion of the program.

5.2.2 FGD Waste Leachate-Liner Compatibility Studies (U.S. Army Engineer WES)

A program to assess the use of liners to contain FGD wastes in disposal ponds is being conducted by the U.S. Army Engineer WES, Vicksburg, Mississippi. An experimental program to determine the compatibility of 18 liner materials with FGD wastes, liquors, and leachates has been defined. Estimates of liner lifetimes will be made on the basis of both a one- and a two-year exposure of the liners to the wastes. The economics of FGD disposal by ponding will then be assessed. The cost of the liner materials and placement will be included, as well as associated and construction costs. The program was initiated July 1975 and is scheduled to be conducted over a period of 36 months.

Ten chemicals will be admixed into soil; six sprayon-type materials and two flexible liners have been selected for exposure to two FGD wastes. Both FGD wastes will be from plants burning eastern coal, one from a lime-scrubbed flue gas and the other limestone. A summary of the liner materials and source of the sludges is shown in Tables 23 and 24. The 18 liner materials will be exposed in a temperature-controlled environment, within a total of 72 cells designed to simulate a sludge depth of approximately 30 ft.

Table 23. LINER MATERIALS

Material	Material Type	Manufacturer
Sprayon Type		
DCA-1295	Polyvinyl acetate	Union Carbide
Dynatech Formulation 267	Natural rubber latex	Dynatech Research and Development Co.
Uniroyal	Natural latex	Uniroyal, Inc.
Aerospray 70	Polyvinyl acetate	American Cyanamid
AC 40	Asphalt cement	Globe Asphalt
SSK	Slow setting cationic emulsified asphalt	Globe Asphalt
Admixes		
Cement	-	Dundee Cement Co.
Lime	-	Williams Keith Lime Co.
Fly Ash	-	Amax Fly Ash Co.
Cement with Lime	-	-
Cement with Fly Ash	-	-
Lime with Fly Ash	-	-
M179	Polymer bentonite blend	Dowell Div. of Dow Chemical
Guartec (UF)	A light grey powder	General Mills
Analine, Furfural	-	GAF Corp (Analine) and General Mills (furfural)
Asphalt Concrete Paving	-	Local Contractors
Prefabricated Membranes		
Liner	Elasticized polyolefin (30 mil)	The Goodyear Tire and Rubber Co.
T-16	Black neoprene-coated nylon-reinforced fabric	Reeves Brothers, Inc.

Table 24. FGD WASTES

Type of FGD Waste	Source of Coal	Sample Source
Lime-scrubbed	Eastern coal	Duquesne Light Co., Phillips Power Station
Limestone-scrubbed	Eastern coal	Commonwealth Edison, Will County Station, Unit No. 1

Physical property and durability tests such as weight, thickness, density, and tensile strength will be performed on the as-received liner materials and, again, after both a 12- and a 24-month exposure. The leachate from each cell will be measured and analyzed. Daily monitoring of the test cells is planned to observe if any breakthroughs occur.

Currently, the test cells have been designed and are being fabricated. The liner materials are being procured. Testing is expected to begin in March 1976. An interim report midway through the program and a final report are planned.

5.2.3 Lime and Limestone Wet Scrubbing Waste Characterization (TVA)

The effects of scrubber operating conditions on FGC waste characteristics are being correlated in this program, which is part of an interagency agreement with TVA, Power Research Staff, Chattanooga, Tennessee. The FGC waste materials from the TVA Shawnee scrubber facility will be characterized and the physical and chemical properties correlated with scrubber operating conditions. The goal of the program is to determine the feasibility of controlling waste characteristics to improve disposal and utilization economics.

Correlation of the Shawnee scrubber operation and sludge characteristics is scheduled for completion by the middle of calendar year 1977 with a milestone report available late in calendar year 1976.

Settling rates, settled bulk density, and percent solids were determined for seven samples obtained from the Shawnee TCA and venturi scrubbing systems. Although the amount of preliminary data is limited, it appears that the lime and limestone slurries may be differentiated by both settling behavior and settling rate. Slurries from the lime scrubbing operation appear to settle and approach compaction smoothly, while those produced in the limestone system show a noticeable and reproducible increase in settling rate immediately before, or upon the onset of, compaction. The mechanism for this behavior has not as yet been defined.

A comparison was made of the results of sludge settling rate tests as performed by TVA at Muscle Shoals and in the chemical laboratory at the Shawnee test facility. The results did not show any systematic, significant differences between the Dorr-Oliver method used at Shawnee and the static test method employed at Muscle Shoals. SEM photographs of the samples show the calcium sulfite hemihydrate $CaSO_3 \cdot 1/2H_2O$ occurs in a variety of textures. In the TCA-limestone system, the sulfite occurs as individual platey crystals and a few rosettes of thin crystals. The sulfite solids from the venturi-lime system generally occur as compact, spherical aggregates which result in faster settling rates. The mechanism of aggregate formation is not known but can have a significant effect on the physical behavior of the solids.

Although no correlations between operating parameters with chemical or physical properties of the waste materials have been defined, there is an inverse relationship identified between stoichiometric ratio and $CaSO_3 \cdot 1/2H_2O$ crystal size. Since there is a wide variation in crystal size within a given sample, usually spanning more than two orders of magnitude, it is difficult to arrive at a meaningful estimate of the average crystal size. However, this qualitative relationship was reported as easiest to observe in extreme cases as when one sample with a stoichiometric ratio of 1.03 was compared to another with a ratio of 1.43. The failure to determine other mathematical relationships is viewed as a result of the relative sparsity of the data at this point, and further work is continuing to analyze additional samples.

Significant differences in filtration rates relative to those usually encountered were observed with venturi lime slurries. The filter cake sample taken at a time when filtration rates were exceptionally high showed large, well-formed platey crystals of $CaSO_3 \cdot 1/2H_2O$, whereas the sample obtained during a period of poor filtration consisted of much smaller crystals. Therefore, sludge samples obtained from the venturi clarifier underflow and the dried solids produced at the drum filter installed in the same process stream were examined. Infrared analyses reveal no characteristics significantly different from other samples.

Characterization work was also performed upon various samples taken from the demister sections of the TCA and venturi during routine mechanical inspections. The as-received samples were reported to be of a mud-like consistency, containing lumps which appeared as a homogeneous unlayered structure. SEM photographs of the dried solids of these samples are being evaluated.

Work is continuing toward the development of a practical method of quantitative x-ray analysis of dried solids components, the objective being to provide a means of determining the distribution of sulfate and sulfite species within a sample. Preliminary results indicate that this method will not determine the sulfate ion concentration with the required precision at the levels currently being observed in the scrubber solids. The decision to implement this analytical method or to terminate its developmental work is expected to be made shortly.

5.2.4 Dewatering Principles and Equipment Design Studies (Auburn University)

This project to be conducted by Auburn University, Auburn, Alabama, will consist of an examination of current dewatering equipment design principles to determine their applicability for use on FGC wastes. Laboratory settling and other tests will be conducted to determine the behavior of FGC wastes. Subsequently, equipment design studies based on FGC waste behavior are planned. This will be followed by laboratory bench tests of the dewatering equipment design concepts. Further testing of promising developments may be conducted if there is sufficient interest expressed by private industry.

5.3 PROCESS ECONOMICS STUDIES

Economic studies are interwoven within most of the various projects. Assessment of process technology or environmental impact includes an examination of the economics involved. However, those primarily related to economics are discussed in this section and include

(1) conceptual design and cost studies for current disposal practices and (2) gypsum by-product marketing studies. Both are being conducted by TVA.

5.3.1 Conceptual Design and Cost Studies of Alternative Methods for Lime and Limestone Scrubbing Waste Disposal (TVA)

In this study by TVA, Office of Agricultural and Chemical Development, Muscle Shoals, Alabama, several FGC waste treatment methods and disposal methods will be selected for detailed economic evaluation.

In disposal of the wastes from lime and limestone scrubbing processes, numerous design and processing options are available. These include variations in dewatering techniques and fly ash content. Waste treatment such as forced oxidation (to gypsum) and chemical fixation includes a number of alternatives. Disposal site characteristics, i.e., location, ponding (with and without liners), and landfill, comprise another set of options.

A survey of the available technology has begun, including costs for commercially available and developed FGC waste disposal systems. The TVA Shawnee field disposal evaluation and engineering cost analysis being performed by The Aerospace Corporation (Section 5.1.1) is expected to provide significant visibility in defining direction for the study.

Selection of the most representative commercial alternatives with definition of design and cost premises to reflect practical applications is planned for completion early in 1976. Preparation of flowsheets, material balances, equipment and material lists and layouts, and investment and operating cost information for comparing the various alternatives will be available thereafter. All major options and variables will then be analyzed. The analysis will include the use of a cost-oriented computer program being developed to project all lime and limestone processing costs. A final report is scheduled for completion in April 1977.

5.3.2 Gypsum By-Product Marketing Studies (TVA)

This project is a task of the conceptual design and cost study of the alternative methods for lime and limestone scrubbing waste disposal. It is being conducted by TVA, Office of Agricultural and Chemical Development, Muscle Shoals, Alabama, in an interagency agreement with EPA.

A preliminary study conducted by TVA during early 1974 indicated that production and sale of abatement gypsum to the wallboard industry in the United States might offer a substantial economic advantage over FGC waste disposal.[17] A series of detailed market studies on by-product sulfuric acid and elemental sulfur in the United States were also conducted for EPA by TVA.[18] These studies involved a transportation cost model and a power plant SO_2 emissions inventory, which were established for the states east of the Rocky Mountains. These studies provided a significant step toward a more detailed evaluation of the economics of using gypsum that may be formed in an SO_2 abatement process.

The current project includes a detailed assessment of by-product gypsum production and market potential. Data will be obtained on the development, design, and operation of leading processes, flow diagrams, and material balances, i.e., Chiyoda, carbon absorption, and $CaSO_3$ oxidation. Detailed investment and operating cost estimates will be prepared for two of these processes. The current sources, production, and market statistics for gypsum will also be presented. In addition, a comprehensive assessment will be made for marketing the gypsum in wallboard outlets in the United States. The most likely candidate power plants will be defined, and expected transportation costs and possible net sales revenue will be projected for the selected plants.

Work on process evaluation has begun, and selection of two processes is expected shortly. Detailed analysis of the marketing data is scheduled to begin in July 1976, with completion of the project in late 1976.

5.4 ALTERNATIVE FGC WASTE DISPOSAL METHODS

The intent of work in this area is to assess the potential and the environmental impacts associated with disposal of FGC wastes in mines and in shallow and deep ocean sites.

5.4.1 Evaluation of Alternative FGC Waste Disposal Sites (A. D. Little)

FGC waste disposal alternatives to ponding and landfilling are being evaluated in this program being conducted by A. D. Little, Inc., Cambridge, Massachusetts. Initially, an assessment will be made of the potential environmental impact of the disposal of untreated and chemically treated FGC wastes in deep and surface mines and in the ocean. State and federal regulatory restrictions applicable to such disposal will be identified and assessed with regard to their adequacy in protecting the environment, and criteria will be defined as appropriate. Realistic approaches, if any, for implementing ocean or mine disposal systems within regulatory and other defined constraints will be identified. Although environmental effects and operational safety are the primary considerations, an assessment will also be made of the costs of promising disposal systems including conceptual designs. Recommendations will include plans for a second phase that includes subscale pilot demonstrations of such a size that design data for full-scale operations can be obtained.

The first phase is an eight-month project that was initiated in late July 1975. Availability of a final report is planned subsequent to completion in April 1976.

One of the significant project tasks is to identify and characterize the physical and chemical properties of both untreated and treated FGC waste by location, process type, and potential quantity produced. As of December 31, a compilation of FGC waste data was completed. Sources were primarily from the U. S. Army WES and The Aerospace Corporation work. Assessment of the impacts of the waste disposal was also begun. Information on properties of FGC wastes unique to the disposal in the marine and mine environment is not available, and some experiments may be conducted to obtain these data prior to defining Phase II conditions for this program. These include such data as sulfite ion oxidation rates in sea water and the impact of sulfite oxidation on dissolved oxygen concentrations. Assumptions on the rates of oxidation suggest a basis for some concern over potential short-term oxygen depletion in situations involving concentrated dumping of $CaSO_3$-rich sludges and the toxicity of the sulfite itself.

In addition to the determination of the physical fate of wastes, the biological impact potentials are being assessed. The effect of trace contaminants is also being evaluated. This effort will be based on the characterization of differing chemical backgrounds in potential dumpsite environments using recently acquired field data from the East and Gulf Coast sampling programs.

The project includes a review of ocean monitoring and policing policy, as well as navigational aids, technology monitoring, biological parameters, and equipment monitoring. Costs of a typical monitoring and policing policy are being included, together with costs of a typical monitoring cruise and the ensuing laboratory analyses.

In the assessment of the disposal of sludges in the mines, a set of assumptions was developed for each general mine case in order to provide a basis for quantifying, as much as possible, the potential impact of the sludge under different conditions. Assumptions included the nature of aquifers, groundwater characteristics, hydraulic gradients, and the effect of a variety of placement techniques on the physical properties of the sludge. These assumptions are being used to evaluate the technical and environmental impacts of sludge disposal options.

An evaluation of federal and state regulations related to sludge disposal is being conducted. An inventory of federal laws relative to mine disposal was made, and an assessment of their adequacy is under way. The use of FGC wastes as a soil amendment is also being reviewed. When compared with lime and sewage sludge, the use of FGC wastes does not appear to be promising.

Both the ocean and mine disposal assessments are scheduled for completion early in calendar year 1976. The results of the assessment work will be used as the basis for completing a conceptual system design for promising disposal options.

5.5 NEW FGC WASTE UTILIZATION METHODS

Utilization projects include development of (1) a process for FGC waste conversion (to sulfur and calcium carbonate), (2) pilot studies of fertilizer production (using the waste as a filler material and a source of sulfur), (3) use of FGD gypsum in portland cement manufacture, and (4) FGC waste beneficiation studies.

5.5.1 Lime and Limestone Scrubbing Waste Conversion Pilot Studies (Pullman Kellogg)

A study is planned to evaluate the Kel-S process, which produces elemental sulfur as an alternative to throwaway disposal of FGD lime and limestone wastes. The project will be approximately 11 months in duration. It involves a cost-shared contract currently under negotiation with Pullman Kellogg, Houston, Texas, to conduct pilot-plant scale evaluation of several key steps in the Kel-S process.

The process converts FGD wastes obtained from lime and limestone scrubbers to elemental sulfur. It also produces calcium carbonate, $CaCO_3$, which can be recycled in the SO_2 scrubbing system. FGD waste will be reduced to calcium sulfide, CaS, in a continuously rotating kiln. The CaS is then reacted with hydrogen sulfide, H_2S, which is available from the recovery unit and forms calcium hydrosulfide, $Ca(HS)_2$. The $Ca(HS)_2$ is dissolved in water and the solution is filtered. The cycle is closed by reaction of the $Ca(HS)_2$ with CO_2-rich gas available from the drying kiln. The reaction with CO_2 forms H_2S and also $CaCO_3$, which is precipitated. Half of the H_2S is returned to react with the CaS, and the remainder is converted to elemental sulfur in a conventional Claus unit. The $CaCO_3$ is recycled to the scrubber system.

It is expected that design and operating data will be obtained to permit scaleup of the process to a prototype integrated system that can be operated in conjunction with a power plant FGC system.

5.5.2 Fertilizer Production Using Lime and Limestone Scrubbing Wastes (TVA)

The use of lime and limestone scrubbing wastes as a filler material and source of sulfur in granular fertilizers is being evaluated. The work is being performed by TVA, Office of Agricultural and Chemical Development, Muscle Shoals, Alabama, as part of an interagency agreement directed toward the evaluation of the utilization or disposal of FGC wastes.

Results from previous TVA bench-scale laboratory tests and small field plot application tests with rye grass were sufficiently promising to warrant additional work on a pilot-plant production basis. In addition to the pilot plant evaluation, the technical, economic, and environmental impacts will be studied as a result of producing and using granular fertilizer from scrubber wastes. Specific tasks include (1) determining compatibility factors involved in mixing and storing the fertilizer with conventional fertilizer, (2) conducting of field plot tests with the pilot-plant produced fertilizer, and (3) assessing the effects of trace and toxic materials relative to those in conventional fertilizers. Marketing studies of the scrubber-waste based fertilizer are also planned.

The pilot plant production and the storage compatibility tests are scheduled for completion in 1976. Long-term agronomic testing is planned to begin in 1977 and extend through 1979.

A flow diagram of the pilot plant process is shown in Figure 21. Plant production is rated at 3000 lb/hr. Efforts through the end of 1975 involve modifications to the existing pilot plant to handle the FGC waste, including the installation of a pump, waste storage tank, and agitators.

Initial pilot plant tests were conducted, using sludge produced at the 1-MW limestone pilot unit located at the TVA Colbert Steam Plant.

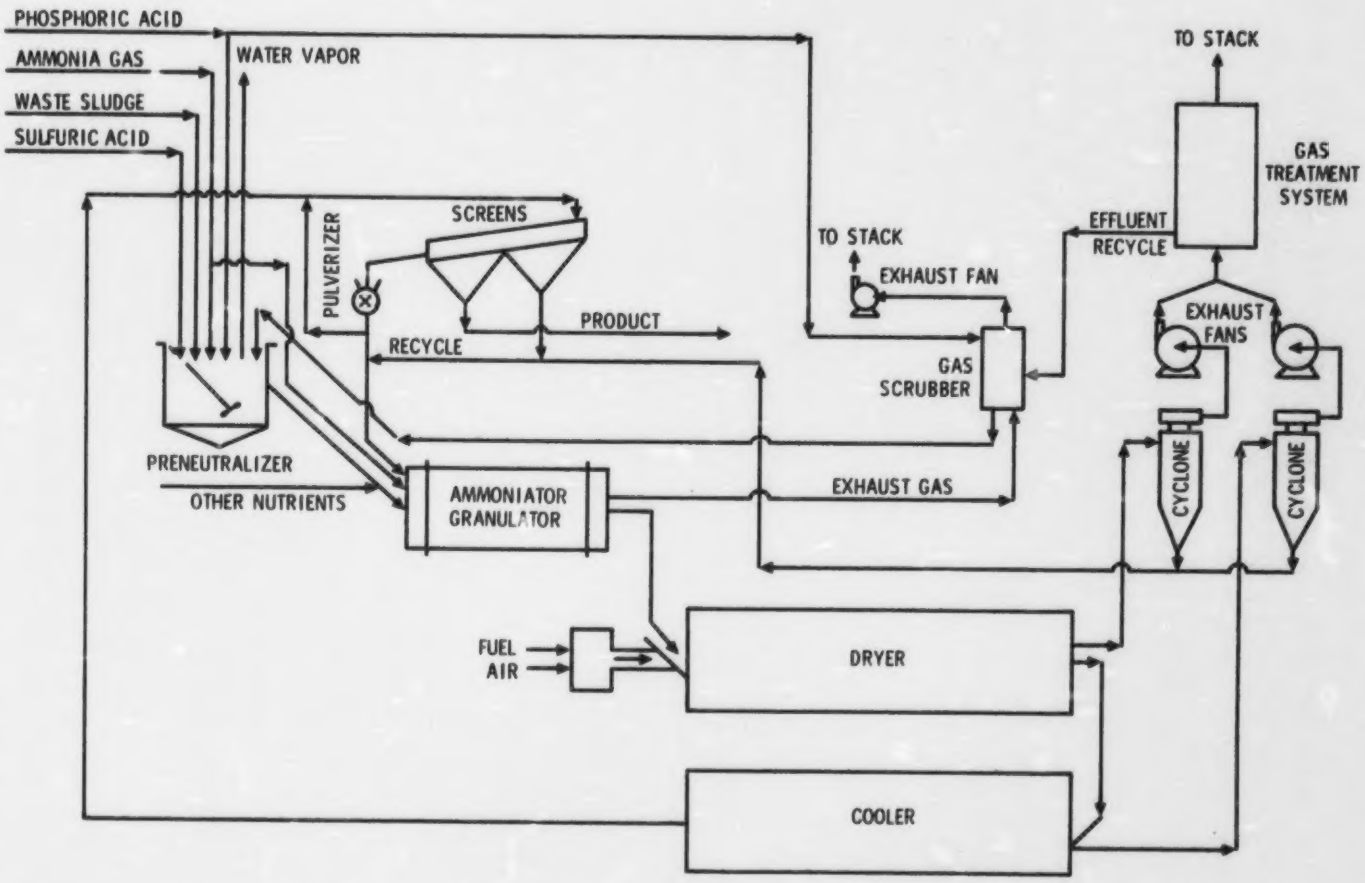
PHOSPHORIC ACID
AMMONIA GAS
WASTE SLUDGE
SULFURIC ACID
WATER VAPOR
PULVERIZER
SCREENS
PRODUCT
RECYCLE
PRENEUTRALIZER
OTHER NUTRIENTS
AMMONIATOR GRANULATOR
FUEL
AIR
DRYER
COOLER
TO STACK
EXHAUST FAN
GAS SCRUBBER
EXHAUST GAS
EFFLUENT RECYCLE
TO STACK
GAS TREATMENT SYSTEM
EXHAUST FANS
CYCLONE
CYCLONE

Figure 21. Process for the production of solid granular fertilizer material from scrubber sludge

Introduction of sludge, phosphoric acid, and ammonia into the preneutralizer resulted in severe foaming. The preneutralizer was then operated with only the acid and ammonia in the conventional ammonium phosphate mode. The sludge and the ammonium phosphate from the preneutralizer were then fed to the drum granulator. A number of sludge feed rates were tried, and those resulting in acceptable granulation rates have been defined.

A specially constructed preneutralizer to eliminate the problems encountered is planned. It includes alternative methods and locations for adding the sludge, acid and ammonia. Improved agitation and foam breaking methods are planned. Development of the preneutralizer modifications is important so that the heat of reaction can be effectively utilized in reducing the solids content of the incoming sludge.

Development of the granulation and processing steps is planned after satisfactory operation of the preneutralizer is obtained.

5.5.3 Use of FGC Gypsum in Portland Cement Manufacture [South Carolina Public Service Authority (SCPSA)]

Laboratory and operational equipment tests will be conducted by the Santee Portland Cement Corporation with SCPSA to determine the acceptable range of variability in the FGD gypsum quality, as well as other potential operational problems. Other uses of FGD gypsum, such as road base material, will be tested in the laboratory and under operational conditions. In addition, a full-scale evaluation of the process is planned utilizing the FGD equipment of a utility coal-fired power plant and a portland cement manufacturing facility.

5.5.4 FGD Waste and Fly Ash Beneficiation Studies (TRW)

A conceptual design and cost study of a TRW proprietary process that produces sulfur, alumina, and dicalcium silicate is planned. Potential uses of the alumina and dicalcium silicate are in the production of aluminum and cement, respectively. If the economics are favorable, bench-scale laboratory tests will be planned to define the range of operating conditions for each of the significant processing steps and to determine probable yields and purity of products. If process viability is established, pilot-plant scale testing may then be performed to obtain design data for full-scale equipment.

5.6 IMPROVEMENT OF OVERALL POWER PLANT WATER USE

The program to improve power plant water use is a single project to study methods to minimize water losses and to recycle or reuse waste water discharges.

5.6.1 Assess and Demonstrate Power Plant Water Recycle and Reuse (Radian)

A technical and economic study is being conducted by Radian, Inc., Austin, Texas, to assess the options for the recycle or reuse and treatment of water for coal-fired power plants. The primary objective is to define ways to minimize water consumption and the discharges of waste water. The basic program will be 13 months in duration.

Computer models are being prepared to simulate the existing plant operations. With these models, predictions of plant operations will be obtained and compared to actual plant operations. This method will be used to verify the validity of the models for use in the technical assessment of various water recycle and reuse options. The most attractive options for each of the plants will be selected, and engineering cost estimates will be made for each plant. The estimates will include capital, installation, and operating costs.

Three plants have been selected for water system characterization and analysis, and the addition of two other plants is planned. On the basis of screening criteria of location, availability, site characteristics, and timing, the three plants selected were the Four Corners Plant of Arizona Public Service, the Public Service of Colorado Comanche plant, and the Bower plant of Georgia Power Company. These were chosen to represent regions in the United States where water recycle or reuse is advantageous due to high water costs, limited availability, or treatment and disposal problems. The basic characteristics of the plants are shown in Table 25.

Samples from each of the three plants have been collected and analyzed. Preliminary simulation schemes for modeling the existing plant processes and operations have been completed, and the data input will be finalized after completion of the laboratory analyses from the sampling trips.

In order to establish the scaling potential criteria of $CaCO_3$ and $Mg(OH)_2$ for use in the water recycle and reuse computer model simulations, laboratory experiments have been conducted. In these experiments, steady-state precipitation rates as a function of solution supersaturation were conducted with $CaCO_3$ and $Mg(OH)_2$.

In support of the model analyses, experiments are required to characterize ash dissolution and to determine the mass transfer of CO_2 from the atmosphere to process slurries and ponded ash. Thereafter, simulations of existing plant operation to validate the model will begin.

Precipitation kinetics experiments required to define the critical relative saturations for $CaCO_3$ tests are complete, and those for $Mg(OH)_2$ are in progress. Upon completion of this task and characterization of ash to determine CO_2 mass transfer between the atmosphere and process vessels and ash ponds, the simulations of existing plant operations and validation of the model will begin.

The technical assessment will be performed on the basis of evaluating various water recycle and reuse options and strategies for each of the representative plants on the design or design installation, operability, and treatment effectiveness. It is expected that the sensitivity to the various parameters will be determined and illustrated. Rough cost estimates of the most attractive viable options as defined by the technical assessment will then be made, and the overall optimum recycle or reuse option based on technical and economic considerations will be defined. The results of the study including recommendations for each plant, further assessments, testing, or field demonstrations will be included in the final report.

Table 25. PLANTS SELECTED FOR WATER RECYCLE AND REUSE STUDY[a]

Utility	Station	Location	Capacity, MW	Type of Cooling[b]	Ash Handling[c]	Particle Control[d]	SO_2 Control[e]
Arizona Public Service	Four Corners,	Farmington, New Mexico	1600	CP	WSB WSF	Cyclones, ESP, venturi	UC
Public Service of Colorado	Comanche	Pueblo, Colorado	350	WCT	WSB	ESP	None
Georgia Power Co.	Bowen	Taylorsville, Georgia	1595[f]	WCT	WSB WSF	ESP	None

[a] Reference 20.

[b] Wet cooling tower (WCT); cooling pond (CP).

[c] Wet sluicing of bottom ash (WSB); wet sluicing of fly ash (WSF).

[d] Electrostatic precipitator (ESP).

[e] Under construction (UC).

[f] Plant capacity as reported in Federal Power Commission (FPC) Form 67 data sheet; present capacity is 3200 MW (4 units).

5.7 EPA IN-HOUSE RESEARCH

EPA is conducting pilot plant experiments on forced oxidation of FGD scrubber sludge.[19] Primary objectives of the project include complete limestone utilization, maximum oxidation efficiency of calcium sulfite to calcium sulfate without catalysts or mechanical means, and improved oxidized slurry settling rates. The second and third objectives are related to determining the feasibility of forming usable gypsum as a by-product from the FGD process.

In order to assess the characteristics of the gypsum from a utilization standpoint or its suitability as a disposal product without the need for further chemical treatment, Aerospace is conducting chemical and physical characterization tests of oxidized wastes formed under a variety of conditions:

a. Limestone scrubbing without fly ash
b. Limestone with fly ash
c. Effect of chloride ion without fly ash
d. Lime scrubbing without fly ash

The laboratory study has been initiated recently on oxidized samples from conditions a and b. It is expected that results of these analyses will be reported in the next annual report.

SECTION VI

UNIVERSITY-RELATED RESEARCH AND DEVELOPMENT

Several universities were identified as planning or conducting research and development (R & D) work in the flue gas desulfurization (FGD) waste disposal and utilization areas.

6.1 AUBURN UNIVERSITY

Auburn University, Auburn, Alabama, which has conducted work in dewatering of phosphate slimes, is being funded by EPA to perform dewatering experiments and to define dewatering equipment design criteria for flue gas cleaning (FGC) wastes. This project is discussed in Section 5.2.4.

6.2 ILLINOIS INSTITUTE OF TECHNOLOGY

Experimental work is being conducted at Illinois Institute of Technology (IIT), Chicago, Illinois, on a process that utilizes sulfur oxide from flue gas to form a superphosphate fertilizer.

Initial feasibility work was conducted by Dr. R. Peck and Mr. L. Pircon at IIT.[21] Subsequently, they received a grant from the State of Illinois Institute of Environmental Quality to demonstrate certain principles involved in the process. Work on the grant is scheduled for completion in June 1976.

A key element in the process involves the contacting of SO_2 from the gases and acidulating phosphate rock in a heterogeneous phase

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reactor to form a superphosphate fertilizer. Ammoniation can be included to form a granular product. The fly ash formed in the combustion process is not removed upstream of the process and is included in the fertilizer. Detailed information on the process will not be available until patent secrecy limitations are lifted.

Hot house experiments have been performed by the State of Illinois, and field plant studies are planned. Plans for demonstrating the process in utility power plant units of up to 150 MW in size are in the formative stages.

SECTION VII

INDUSTRIAL RESEARCH AND DEVELOPMENT AND OPERATIONAL APPLICATIONS

This section summarizes the work performed by various industrial organizations in the chemical treatment of flue gas desulfurization (FGD) wastes. The operational applications of FGD treatment and disposal are also summarized.

7.1 RESEARCH AND DEVELOPMENT BY UTILITIES

7.1.1 Ontario Hydro[22-24]

Ontario Hydro, Toronto, Canada, has been involved in the study of FGD systems for several years and has studied a broad range of conditions dealing with the disposal of flue gas cleaning (FGC) waste.[22-24] At that time they were burning eastern United States coal exclusively, from Pennsylvania and West Virginia. As a result of long-range coal supply considerations, the use of low-sulfur western Canadian coal is being increased. Currently, emission standards are being met by the use of a blend of the two types or by intermittent use of low-sulfur coal. Since it is expected that this strategy will be utilized in the foreseeable future, the research and development (R&D) activity of Ontario Hydro in FGD scrubbing and disposal has been essentially concluded.

Prior to this decision, FGD research at Ontario Hydro was broad in scope and actively pursued. Laboratory programs evaluating various chemical additives and their effects on the physical properties of treated waste are reported in Reference 23. Table 26 is representative of the mixtures tested and reports the effect on the compactability and permeability of different mix proportions.

In the area of sludge dewatering, the effect of polyelectrolytes on settling, the mechanics involved during the thickening, and the methods of improving the efficiencies of the thickener have been studied. At the pilot scale, thickener-vacuum filtration techniques and a solid bowl continuous centrifuge to determine efficiencies and for comparison purposes have been evaluated. The results of this work will be published in the near future in the Ontario Hydro Research Quarterly.[24]

7.1.2 Southern California Edison

7.1.2.1 Highgrove Plant[22]

Southern California Edison (SCE) is operating a 10-MW lime scrubber at its Highgrove plant to evaluate the horizontal scrubber efficiency when using high-sulfur fuel oil. The SO_2 content in the flue gas is high, about 2000 ppm. The sludge is composed mainly of calcium sulfite, approximately 90 percent $CaSO_3$, which is the opposite of what was reported at Mohave (Section 7.1.2.2). SCE has tested and developed a process to oxidize the calcium sulfite to calcium sulfate with air oxidation and pH control that yields 97 percent oxidation.

7.1.2.2 Mohave Plant[22, 25]

Much of the SCE full-scale sludge-disposal-related research was carried out at the Mohave scrubber installation, Clark County, Nevada and completed in 1975. The flue gas inlet concentration was low in SO_2, and the sludge was composed mainly of calcium sulfate. It was reported that the Mohave sludge dewatered well (60 to 70 percent solids) and was fairly stable without further treatment.

Table 26. MIX CONSISTENCIES WITH VARIOUS ADDITIVES FOR LAKEVIEW GAS SCRUBBER SLUDGE CONTAINING 65 PERCENT SOLIDS

Mix Proportions	Consistency of Mix	Remarks on Compactability
Sludge + 5% Lime Sludge + 10% Lime Sludge + 5% Cement[a] Sludge + 10% Cement	Soft and wet	Both lime mixes were too wet to compact, even after 1 week of retention. The cement mixes were too wet to compact initially but were compactable after 24 hours.
Sludge + 15% Cement Sludge + 52% Fly Ash Sludge + 39% Fly Ash + 5% Cement Sludge + 39% Fly Ash + 15% Cement	Firm and wet	All mixes too wet, although some only slightly, causing some slumping of specimens after removal from mold
Sludge + 65% Fly Ash[b] Sludge + 15% lime Sludge + 39% Fly Ash + 5% Lime[c] Sludge + 65% Fly Ash + 5% Cement[d] Sludge + 65% Fly Ash + 15% Cement	Firm and moist	Ideal mix combinations for compaction
Sludge + 65% Fly Ash + 5% Lime	Firm and dry	Slightly drier than above mixes, but compactable
Sludge + 39% Fly Ash + 15% Lime Sludge + 65% Fly Ash + 15% Lime	Powdery and dry	Too dry and powdery for proper compaction

Condition	Permeability, Coefficient, cm/sec
a	7.6×10^{-6}
b	7.2×10^{-6}
c	5.6×10^{-6}
d	4.0×10^{-6}
Untreated (77% Solids)	9.0×10^{-6}

Dewatering sludge was accomplished in a thickener where both cationic and anionic flocculents were added, one for the fly ash fraction and the other for sulfur products. After settling, the underflow was subjected to chemical treatment. SCE contracted with Dravo and IU Conversion Systems (IUCS) to treat the sludge.

The Dravo process added Calcilox® to the thickener underflow; at times, lime was added for pH control. The resultant mixture was placed in an unlined pond for hardening.

IUCS treated the total annual output from the Mohave Unit No. 1A, 167-MW scrubber system. The material produced, Pos-O-Tec®, was used in a number of synthetic aggregate-related applications:[25]

a. As a landfill in the construction of a housing project; a total of 25,000 tons were placed to reclaim land

b. In the construction of a parking lot

c. As road base by the Mohave County Department of Highways in the construction of Bullhead City streets and county roads. The base was capped with an oil and chip surface course

SCE is not expected to use a chemical treatment process at Mohave for sludge disposal since the calcium sulfate sludge is considered stable, and enough land area exists at the Mohave site to accommodate all the sludge produced for the life of the plant, which is estimated to be 4000 acre-ft.

7.1.2.3 Applications[22]

SCE hopes to develop a market for the oxidized sludge in the wallboard industry and will probably make a 50-ton full-scale wallboard test with Kaiser Cement Company.

Another interest of SCE is to utilize oxidized sludge for agricultural purposes. Gypsum promotes growth of denitrifying bacteria in soils containing a high concentration of nitrates. It has also been found to promote the growth of alfalfa and peanuts and is a useful additive for sulfur-deficient soil.

Other testing has included dewatering studies using thickeners, filters, and centrifuges and drying studies using spray dryers, thermal disc dryers, and kiln dryers. Pelletizing has also been studied.

7.1.3 Southern Services[22,26]

As a result of testing three FGD processes at Plant Scholz (20-MW each), Southern Services, Chattahoochee, Florida, has become involved in both disposal and utilization studies of waste products from the Chiyoda gypsum process. Studies of the chemical treatment of sludge from the Combustion Equipment Associates/Arthur D. Little, Inc. (CEA/ADL) dual-alkali process is also being performed.

Southern Services has conducted bench-scale testing and has to determined the suitability of using Chiyoda gypsum in wallboard manufacturing. Southern Services is also interested in the use of this gypsum as a cement setting retardant and in agricultural applications.[26]

The gypsum produced at the Scholz plant consists almost entirely of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). It has been reported as easy to dewater by centrifuging, and the solids content is typically 80 to 85 percent. The gypsum is composed of 28 percent sand size, 66 percent silt size, and 6 percent clay size material, according to the MIT classification system.

The major portion of the gypsum particles ranged in size from 0.01 to 0.1 mm. As a result of consolidation tests, it was reported that landfilled Chiyoda gypsum could support significant loads without appreciable settlement. However, loads subject to vibration could not be placed on a gypsum landfill because the gypsum tends to liquefy with vibration if the water content of the gypsum does not remain low (approximately 15 percent or less). A range of permeabilities was calculated from the consolidation tests to be 10^{-6} to 10^{-5} cm/sec. In Atterberg limit testing it was found that the Chiyoda gypsum is nonplastic and that it will liquefy when wet and subjected to vibration.

Currently, the gypsum is disposed of in a lined pond equipped with an underdrain. Rain water, percolated through the gypsum, passes through the underdrain and is routed to the ash pond. The water from the underdrain has been sampled monthly since July 1975, and the results of the analyses are reported in Reference 26 (Table 27). In general, with the possible exception of total dissolved solids (TDS), it appears that the leachate poses no water quality problems. Trace element concentrating are low because most of the trace contaminants in the flue gas are removed in the prescrubber. The liquid waste from the prescrubber is neutralized with limestone and routed to a lined settling pond where fly ash, gypsum, unreacted limestone, and $Fe(OH)_3$ (catalyst from mother liquor bleed) settle out.

If TDS in the gypsum leachate poses a problem at a full-scale installation, leaching could be minimized by lining the disposal area or treating the gypsum. Studies are under way at the Scholz plant to test usage of compacted gypsum layer as an alternative to conventional liners. Approximately 1 ft of gypsum will be placed in a 20 × 50 ft level area and will be compacted with conventional compaction equipment. Core samples of the compacted layer will be taken, and their permeability will be determined in the laboratory. Approximately three more feet of gypsum will be placed on top of the compacted layer, and the gypsum and gypsum liner will be allowed to weather. Core samples will be taken periodically to determine if liner permeability varies with time.

The overflow from the settling pond has been sampled and analyzed monthly since July 1975. The analyses, as shown in Table 27, include trace elements as well as major constituents. Concentrations of TDS, iron, mercury, and fluoride in excess of state water quality standards for receiving waters have been measured in the settling pond overflow. Selenium concentrations in excess of U.S. Public Health Service (USPHS) drinking water standards have also been measured in this overflow. However, the settling pond overflow is routed to the Scholz plant ash pond, which ultimately discharges to the Apalachicola River where state water quality standards are applicable. There have been no violations of state water quality standards, as determined by monthly monitoring of the ash pond overflow.

Table 27. EFFLUENT ANALYSES FROM A LINED LIQUID-WASTE SETTLING POND[a]

Parameter	Liquid Purge Settling Pond Overflow	Gypsum Pond Underdrain	State of Florida Water Quality Standards[b]
TDS, mg/ℓ	2000 to 4994[c]	2250 to 2754[c]	500[d]
Total Suspended Solids, mg/ℓ	6 to 393[e]	<1 to 4	-
pH	2.3 to 7.5[c]	6.8 to 7.2	6 to 8.5
Conductivity, µmhos/cm	3050 to 6700	2000 to 2670	500
Temperature, °F	47 to 85	55 to 88	-
Total Calcium, mg/ℓ as Ca	330 to 1100	540 to 644	-
Total Magnesium, mg/ℓ as Mg	39 to 246	14 to 87	-
Total Sodium, mg/ℓ as Na	28 to 65	12 to 67	-
Total Potassium, mg/ℓ as K	0.85 to 2.93	0.47 to 1.65	-
Total Hardness, mg/ℓ as $CaCO_3$	1093 to 3360	1406 to 1830	-
Total Phosphorus, mg/ℓ as P	<0.01 to 0.036	<0.01	-
Dissolved Silica, mg/ℓ as SiO_2	12 to 31	1.5 to 2.3	-
Sulfate, mg/ℓ as $SO_4^=$	1160 to 2750[f]	1370 to 1650[f]	-
Sulfite, mg/ℓ as $SO_3^=$	<1	<1	-
Carbonate, mg/ℓ as $CaCO_3$	0	0	-
Bicarbonate, mg/ℓ as $CaCO_3$	0 to 38	35 to 44	-

(Continued)

Table 27. EFFLUENT ANALYSES FROM A LINED LIQUID-WASTE SETTLING POND[a] (Continued)

Parameter	Liquid Purge Settling Pond Overflow	Gypsum Pond Underdrain	State of Florida Water Quality Standards[b]
Hydroxide, mg/ℓ as $CaCO_3$	0	0	-
Chloride, mg/ℓ as Cl	51 to 138	2.3 to 9.1	250
Carbon Dioxide, mg/ℓ as CO_2	25 to 970	4.8 to 12.0	-
Total Acidity, mg/ℓ as $CaCO_3$	0 to 1080	0	-
Color, standard units	0.5 to 13	0.5 to 8	-
Turbidity, NTU	4.2 to 92.0[c]	0.18 to 1.6	50
Total Aluminum, mg/ℓ as Al	2.10 to 4.80	<0.05 to 0.24	-
Total Arsenic, mg/ℓ as As	<0.01	<0.01	0.05
Total Cadmium, mg/ℓ as Cd	<0.01	<0.01	-
Total Chromium, mg/ℓ as Cr	<0.01 to 0.04	<0.01	0.05[g]
Total Copper, mg/ℓ as Cu	0.06 to 0.60[c]	<0.01	0.5
Total Iron, mg/ℓ as Fe	0.54 to 109.0[c]	0.019 to 0.17	0.3
Total Lead, mg/ℓ as Pb	<0.01	<0.01	0.05
Total Manganese, mg/ℓ as Mn	0.17 to 1.08[h]	<0.01 to 0.32[h]	-
Total Mercury, mg/ℓ as Hg	<0.0002 to 0.0068[c]	<0.0002 to 0.0004	ND[i]
Total Nickel, mg/ℓ as Ni	0.02 to 0.15	<0.01	-
Total Selenium, mg/ℓ as Se	0.016 to 0.13[j]	<0.002 to 0.04	-
Total Zinc, mg/ℓ as Zn	0.26 to 1.3[c]	<0.01	1.0
Oil and Grease, mg/ℓ	<1	<1	15

(Continued)

Table 27. EFFLUENT ANALYSES FROM A LINED LIQUID-WASTE SETTLING POND[a] (Continued)

Parameter	Liquid Purge Settling Pond Overflow	Gypsum Pond Underdrain	State of Florida Water Quality Standards[b]
Nitrate, mg/ℓ as N	20 to 105[k]	4 to 43	-
Chemical Oxygen Demand, mg/ℓ	<1 to 11	<1 to 4.9	-
Fluoride, mg/ℓ as F	4.2 to 27[c]	0.54 to 0.94	1.4 to 1.6[l]
Boron, mg/ℓ as B	1.0 to 4.6[m]	<0.1	-

[a] July through December 1975.[26]

[b] Applicable to receiving waters only after reasonable opportunity for mixing with wastes has been afforded.

[c] These values would violate water quality standards if mixing were not taken into account.

[d] As a monthly average: 1000 mg/ℓ instantaneous.

[e] The EPA effluent guidelines for steam electric power plants for total suspended solids is 100 mg/ℓ maximum for any one day and 30 mg/ℓ for a monthly average.

[f] The USPHS 1962 drinking water standard for sulfate is 250 mg/ℓ.

[g] For total chromium in the effluent discharge, the standard is 1.0 mg/ℓ;
for hexavalent chromium in the effluent discharge, the standard is 0.5 mg/ℓ.

[h] The USPHS 1962 drinking water standard for manganese is 0.05 mg/ℓ.

[i] None detectable (for practical purposes at this time, ND = <0.0002 mg/ℓ).

[j] The USPHS 1962 drinking water standard for selenium is 0.01 mg/ℓ.

[k] The USPHS 1962 drinking water standard for nitrate is 45 mg/ℓ.

[l] Applicable only to waters used for sources of Class 1 water supply; for other waters, the standard for fluoride is 10 mg/ℓ.

[m] The EPA proposed water quality criteria for public water supply intake (October 1973) for boron is 1.0 mg/ℓ.

For full-scale applications, treatment or reduction of the liquid waste may be required by both state and federal regulations. Treatment could be accomplished if the volume of waste were reduced by evaporation. It has been reported that consideration is currently being given by the EPA to demonstrating vapor compression evaporation on the Chiyoda liquid waste at the Scholz plant. Plans to reduce water consumption and the liquid waste stream are being implemented as an approach to a closed loop.

Chiyoda gypsum has been laboratory-tested by a wallboard company and appears to be suitable for wallboard manufacture through small-scale tests. A demonstration test is planned, using 100 tons of Chiyoda gypsum at a wallboard plant in Jacksonville, Florida.

The suitability of Chiyoda gypsum for cement production is being tested by a cement company. Preliminary reports indicate that Chiyoda gypsum can be used as a cement setting retardant.

Agricultural use of gypsum as a calcium source for peanuts is fairly well established in the southeastern region of the United States. Testing the suitability of the Chiyoda gypsum for agriculture began in December 1975 with soil incubation studies at the University of Florida Agricultural Research Center, Quincy, Florida. The first month of soil incubation indicates that application rates of up to 20 tons of Chiyoda gypsum per acre of soil will be feasible. The results of plant response tests will soon be available because test plants (peanuts and soybeans) were planted in soil-gypsum mixtures in early February 1976.

Chemical treatment is also being performed on the sludge from the CEA/ADL dual-alkali process. Fly ash, portland cement, and quicklime are being added to the sludge in various concentrations and combinations so as to define the more promising fixation method. IUCS and Amax have also had an opportunity to test their processes on the sludge material.[22]

Southern Services also plans to conduct economic and engineering evaluations for large-scale sludge-handling systems, such as pumping and conveyors. Plans have been made for prototype and demonstration testing of the phases of study that prove to be promising.

7.1.4 Southwestern Public Service Company[22]

Southwestern Public Service Company, together with Combustion Engineering, is also involved in studying the feasibility of producing structural landfill material from sludge by mixing scrubber solids with local soils found around the plant site.[22] Tests demonstrated that mixtures of soil and sludge could produce a landfill material with significant load-bearing strength. This type or method of approach is reported to be more promising in areas that have a more arid climate.

7.1.5 Electrical Power Research Institute[1]

As a result of its assessment of the complexity and site-specificity of handling and disposing of lime and limestone scrubber, the Electrical Power Research Institute (EPRI) has defined a program which addresses these problems.[1] The projects specifically related to FGD treatment and disposal are covered under the general objective to develop a reliable design basis of lime and limestone scrubbing. The proposed treatment and disposal projects are enumerated in Table 28. Although detailed descriptions of the various tasks were not provided, it appears that four or five projects (Items 1 and 3 through 6 of Table 28) lie in areas of interest similar to the EPA FGC Waste and Water Program. It is anticipated that the EPA program information will be used wherever possible. It has been reported that a memorandum of understanding has been signed by EPRI EPA calling for cooperation in R & D in areas of mutual interest relating to the environmental aspects of producing, transmitting, distributing, utilizing, and conserving electric power.[45]

7.1.6 Commonwealth Edison Company[27]

A project to characterize the sludge produced from the Commonwealth Edison Will County Unit No. 1, Joliet, Illinois, limestone scrubber is reported in Reference 27. Laboratory studies were conducted on treated sludge admixtures to determine the following:

a. Compressive strength

Table 28. EPRI SO_x CONTROL PROGRAM: FGD TREATMENT AND DISPOSAL

1. Evaluate FGD Process Control Capability
2. Low Sulfur and Alkaline Ash Scrubbing Characterization
3. Evaluation of Sludge Dewatering Processes
4. Sludge Composition and Leachability
5. Sludge Fixation Chemistry Guidelines
6. Chemistry Modifications to Improve Reliability and Cost
7. Hardware Modification to Improve Reliability and Cost
8. Diagnostic Support, Eastern Coal
9. Diagnostic Support, Western Coal

b. Permeability

c. Solubility

d. Dissolved solids in sludge supernatant

Considerable data were reported in each category, including properties as a function of curing temperature. Significant and typical results are summarized below.

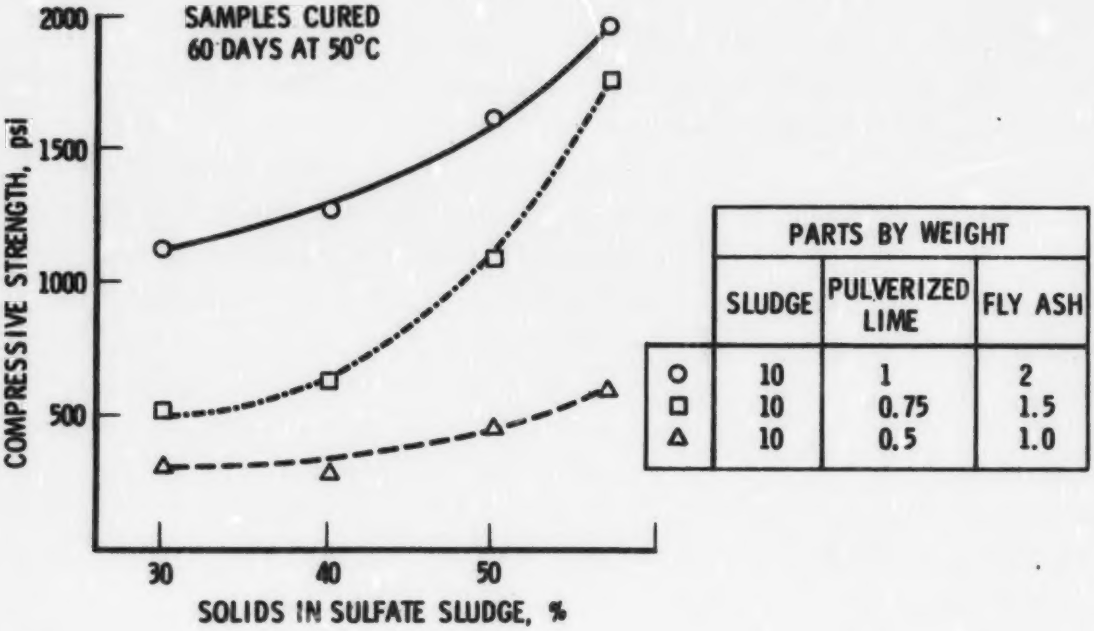
7.1.6.1 Compressive Strength

Over 270 test series were made of various sludge admixture combinations and curing temperatures. Samples were cured in 100 percent relative humidity at 4.4°C (44°F), 22°C (72°F), and 50°C (122°F). Some significant findings of the tests were that the addition of pulverized lime and fly ash or portland cement and fly ash resulted in the most economical and satisfactory solidification of sulfate sludge. Figure 22 illustrates some of the results obtained.

At low temperatures (4.4°C), the laboratory sludge additive mixtures did not harden to any significant degree. Some field mix samples hardened; however, these samples were at room temperature for four days prior to being placed at 5°C for further curing. Curing at 22°C resulted in strengths of about 20 to 25 percent lower than corresponding samples cured at 50°C.

7.1.6.2 Permeability

Permeability coefficients of samples ranged from 10^{-7} to 10^{-10}cm/sec. The permeability was found to be dependent on the solids and additive contents of the sludge. The effect of these parameters is shown in Figure 23. Strength and permeability are generally related to the porosity of a material. The strength and permeability of the hardened sludge as a function of the compressive strengths required for a permeability factor of 10^{-8} and 10^{-7} cm/sec are approximately 650 psi and 250 psi, respectively.



	PARTS BY WEIGHT		
	SLUDGE	PULVERIZED LIME	FLY ASH
○	10	1	2
□	10	0.75	1.5
△	10	0.5	1.0

Figure 22. Sixty-day compressive strength of sulfate sludge, pulverized lime, and fly ash mixtures

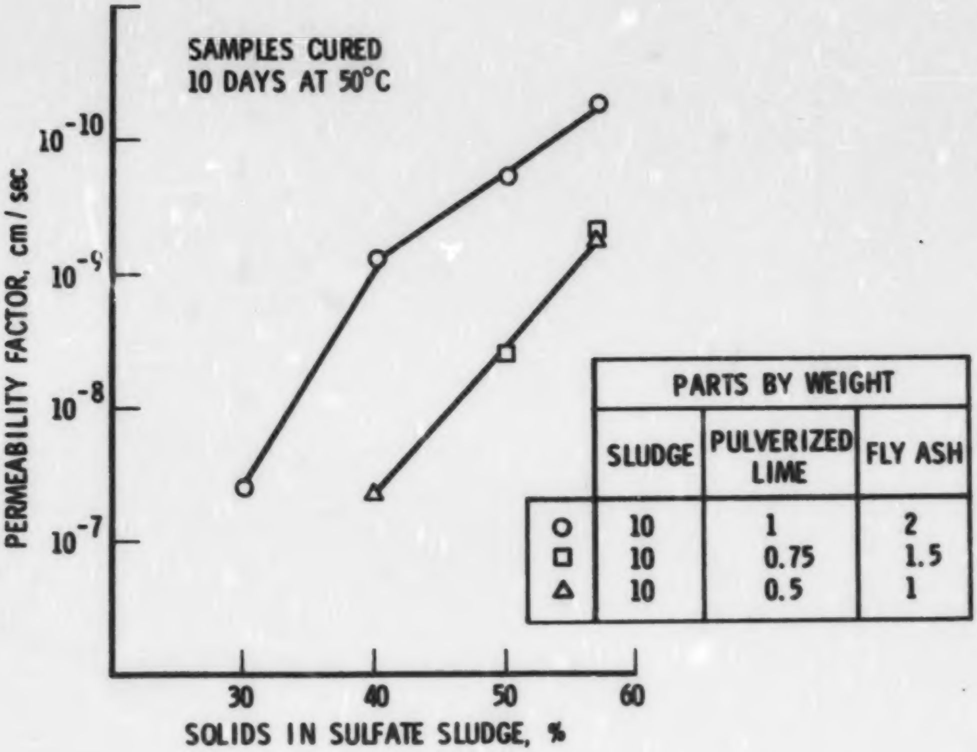


Figure 23. Permeability of sulfate sludge, pulverized lime, and fly ash mixtures

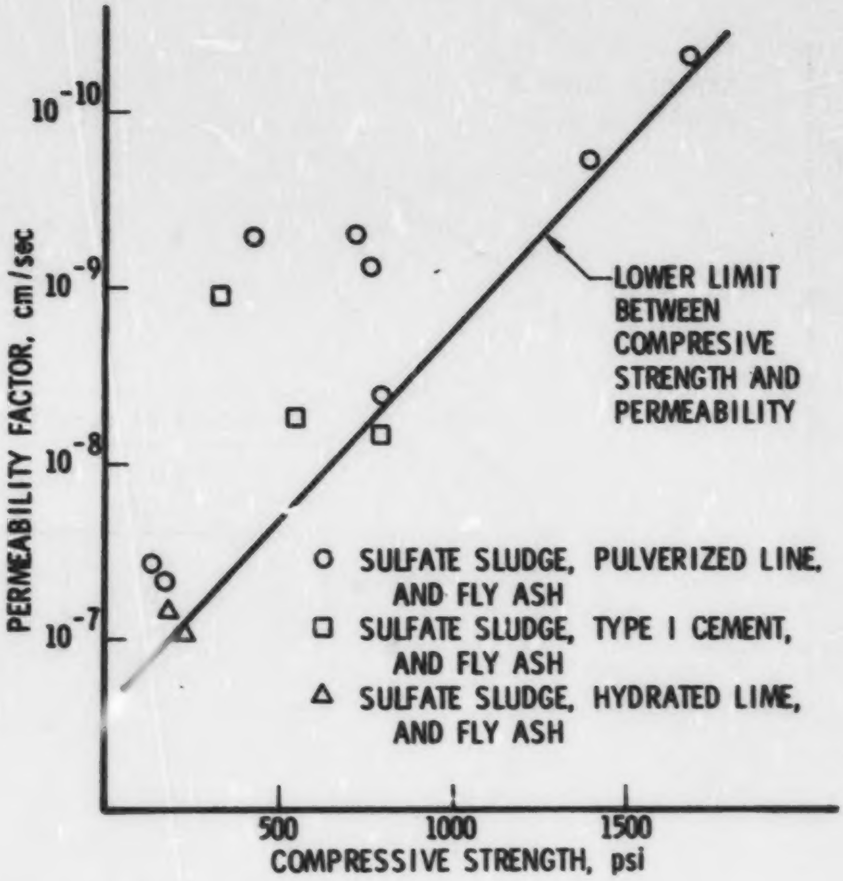


Figure 24. Relationship between compressive strength and permeability

7.1.6.3 Solubility

Solubility of the sludge was characterized as a function of the sulfate concentration in the water which was contacted with sludge. Crushed solidified sludge was used to simulate a severe leaching environment. Two sizes of crushed solidified sludge were used: 0.187 × 0.094 in. (4 × 8 mesh) and 0.012 × 0.006 in. (50 × 100 mesh). Water poured through a filter bed of the solidified sludge was collected and analyzed. Contact time between the water and sludge varied from 5 to 60 min. A series of seven consecutive washings or leachings were analyzed. Results of this test series are given in Tables 29 and 30.

Supernatant of the untreated sludge contained 1640 mg/ℓ of $SO_4^=$ while the highest average $SO_4^=$ content for seven consecutive washings of solidified sludge was 177 mg/ℓ with a 50 × 100 mesh sample in contact with water for 60 min/wash (Table 29). The results show that treatment of the sludge significantly reduces its $SO_4^=$ solubility even when the solidified sludge is in powder form.

The $SO_4^=$ content decreased with increased leaching of the sludge when the first leachate contained over 100 mg/ℓ (Table 30). However, even after the first washing of the 50 × 100 mesh, 60-min contact time sample, the wash water contained only 428 mg/ℓ $SO_4^=$.

The $SO_4^=$ content of the wash water increased with increased contact time, e.g., from 26 mg/ℓ (for 3 to 5 min/wash) to 67 mg/ℓ (for 60 min/wash), Table 29. Generally the $SO_4^=$ concentration decreased with an increase in solids content of the sludge as well as with an increase in quantity of additives added to solidify the sludge.

A sample of 4 × 8 mesh solidified sludge (10 parts of 57 percent solids content sludge plus 0.5 parts pulverized lime and 1 part fly ash) was immersed in a liter of distilled water, and aliquots were taken for $SO_4^=$ analyses at time intervals of up to 60 days. These data are given in Table 31. After 60 days, the $SO_4^=$ content was 241 mg/ℓ. The compressive strength of this sample exceeded 1500 psi and its permeability was 3×10^{-10}.

Table 29. SOLUBILITY OF SULFATE FROM TREATED SULFATE SLUDGE MIXTURES[a]

Composition, parts by weight				Solids in Sludge, %	Particle Size, mesh	Contact Time of H_2O and Sludge per Wash, min	$SO_4^=$ Content, g/l	
Sludge	Pulverized Lime	Type I Portland Cement	Fly Ash				Average of 7 Consecutive Washes	Range of 7 Consecutive Washes
10	1		2	57[b]	4 × 8	3 to 5	0.012	0.010 to 0.014
10	0.5		1	57[b]	4 × 8	3 to 5	0.023	0.020 to 0.027
10	1		2	50	4 × 8	3 to 5	0.011	0.009 to 0.013
10	1		2	50	50 × 100	~60	0.017	0.014 to 0.020
10	0.5		1	50	4 × 8	3 to 5	0.028	0.024 to 0.031
10	1		2	40	4 × 8	3 to 5	0.026	0.022 to 0.030
10	0.5		1	40	4 × 8	3 to 5	0.033	0.032 to 0.034
10		1	2	40	4 × 8	3 to 5	0.040	0.038 to 0.044
10		0.5	1	40	4 × 8	3 to 5	0.027	0.023 to 0.035
10	1		2	40	4 × 8	~60	0.067	0.039 to 0.104
10	1		2	40	50 × 100	~60	0.177	0.094 to 0.428

[a] All mixtures cured 10 days at 45°C and an additional 30 days at 25°C.

[b] Sulfate content of supernatant was 1.640 g/l.

Table 30. SULFATE ANALYSES OF WATER IN CONTACT WITH TREATED SOLIDIFIED SLUDGE

Composition, parts by weight			Solids in Sludge, %	Dry Sample Weight, g	Particle Size, mesh	Contact Time of H_2O and Sludge, min	Sulfate Content of Water in Consecutive Washings, mg/ℓ						
Sludge	Pulverized Lime	Fly Ash					1	2	3	4	5	6	7
10	1	2	43[a]	20	4 × 8	3 to 5	11.6	10.0	14.0	11.0	12.8	13.2	11.9
10	0.5	1	43[a]	20	4 × 8	3 to 5	23.4	27.4	23.4	20.1	19.9	21.8	23.4
10	1	2	50[b]	20	4 × 8	3 to 5	11.9	9.4	9.4	11.6	12.4	12.4	12.8
10	0.5	1	50[b]	20	4 × 8	3 to 5	-	31.2	28.6	24.4	25.6	26.0	29.2
10	1	2	50[b]	20	50 × 100	3 to 5	18.8	14.0	15.4	17.6	16.5	18.8	20.0
10	1	2	57	20	4 × 8	3 to 5	30	24.4	23.2	22.0	23.2	23.4	25.4(114)[c]
10	1	2	57	20	4 × 8	~60	104	94	80	64	42	39	47
10	0.5	1	57	20	4 × 8	3 to 5	33.9	33.6	33.6	33.3	31.6	32.2	34.2
10	1	2	57	20	50 × 100	~60	428	188	177	120	133	102	94
10	1	2	57	20	4 × 8	3 to 5	44.3	39.4	37.6	38.4	40.5	41.2	37.6
10	0.5	1	57	20	4 × 8	3 to 5	35	28.4	23.2	26.4	25.0	24.8	26.0

[a] Sulfate content of supernatant was 1640 mg/ℓ.

[b] Sulfate content of supernatant was 1480 mg/ℓ.

[c] Additional wash in which the sample was exposed to H_2O for ~60 min.

Table 31. SULFATE CONTENT OF 100-mℓ ALIQUOTS FROM 20 g OF 4 × 8 SOLIDIFIED SLUDGE[a]

Time of Immersion		Sulfate Content of H_2O, mg/ℓ
0.5	hr	44.2
1	hr	54.5
2	hr	56.0
4	hr	74.0
8	hr	78.8
24	hr	85.6
7	days	112.0
60	days	241.0

[a] 10 parts by weight of sludge (57% solids), 0.5 parts by weight of pulverized lime, and 1 part by weight of fly ash in 1ℓ of H_2O.

7.1.6.4 TDS in Supernatant

The supernatant of the sulfate sludges tested contained 1.480 and 1.640 g/ℓ of sulfate and a TDS content of 4.160 g/ℓ. Numerous compounds were added to the supernatant in an attempt to reduce its $SO_4^=$ and TDS content. One compound was successful in reducing the $SO_4^=$ and TDS content rapidly. This compound when added at levels of 6.25 g/ℓ of supernatant reduced the TDS to approximately 0.7 g/ℓ and the $SO_4^=$ content to approximately 0.5 g/ℓ.

7.2 UTILITY POWER PLANT APPLICATIONS

Full-scale experience and future plans relating to FGD chemical treatment and disposal by utilities are summarized in Tables 32 and 33. A total of 13 units, representing 8 power plants totaling 5205 MW, are currently committed to initiate by 1979 the chemical treatment of wastes prior to disposal. Three stations (767 MW) are now in operation; three others (1413 MW) will start up by the end of 1976, and seven others have made definite commitments to begin by 1979. Also a number of facilities representing 4338 MW equivalent are identified as scrubbing and disposing untreated FGC wastes in lined ponds in 1976.[5,28]

Table 32. FGC CHEMICAL TREATMENT PROCESSES: UTILITY PLANT CHARACTERISTICS

Utility	Power Station	Station Size, MW	Coal Characteristics			FGD Absorbent	FGD Installation	FGD Startup	Scrubber Size, MW	Particulate Control Device Upstream of Scrubbers	Scrubber System	By-pass	Ref.
			% S	% Ash	Btu/lb								
Commonwealth Edison	Will County, Unit No. 1	167	2 (1974) 1 (1975)	10	9,900	Limestone	Retrofit	Feb 1972	167	Electrostatic precipitator (ESP) used only when FGD not in use	Two venturi and countercurrent tray absorber modules. B & W	Yes	29-31
Duquesne Light Co.	Phillips	410	1.0 to 2.0	18	11,000	Slaked lime	Retrofit	Jul 1973	410	Mechanical cyclones followed by ESP, Research-Cottrell; venturis	One 2-stage variable throat venturi module processing 125 MW; four single-stage modules processing remainder; Chemico	Yes	29, 32
Duquesne Light Co.	Elrama	510	2+	18	12,000	Hydrated lime with switch to quicklime as soon as possible	Retrofit	Nov 1975	510	Mechanical cyclones followed by ESP; venturis	Five single-stage venturis, Chemico	Yes	29, 33, 34
Southern California Edison (SCE)	Mohave, Unit No. 1	790	0.5 to 0.8	10	11,500	Limestone (lime alternative)	Retrofit	Jan 1974	170	ESP, Research-Cottrell	Vertical TCA module. Universal Oil Products (UOP); test completed Jul 1975	Yes	29, 35, 36
	Mohave, Unit No. 2	790	0.5 to 0.8	10	11,500	Lime (limestone alternative)	Retrofit	Nov 1973	170	ESP, Research-Cottrell	Horizontal 4-stage counter-current module, SCE; tests completed, Feb 1975; 170-MW prototype unit to Public Service Cornero Station	Yes	29, 35, 36
Central Area Power Coordination (CAPCO) Group	Bruce Mansfield, Unit No. 1	825	4 to 5	8 to 10		Lime	New	Apr 1976	825	None	2-stage scrubbers, Chemico		29, 37, 38
Ohio Edison Co. Duquesne Light Co. Cleveland Electric Co. Toledo Edison Co. Pennsylvania Power Co. (operator)	Unit No. 2	825	4 to 5	8 to 10		Lime	New	Apr 1977	825	None	2-stage scrubbers, Chemico		29, 37, 38
Louisville Gas and Electric Co. (LG&E)	Cane Run, Unit No. 4	178	3.5 to 4.0			Lime	Retrofit	Jun 1976	178		American Air Filter		29
	Cane Run, Unit No. 5	183	3.5 to 4.0			Lime	Retrofit	Dec 1977	183		Combustion Engineering		29
	Cane Run, Unit No. 6	277	3.5 to 4.0			Lime	Retrofit	Sep 1978	277		Not selected		29
	Mill Creek, Unit No. 3	425	3.5 to 4.0			Lime	New	Jul 1977	425		American Air Filter		29
	Mill Creek, Unit No. 4	425	3.5 to 4.0			Lime	New	Jul 1979	425		Not selected		29
Columbus and Southern Ohio Electric	Conesville, Unit No. 5	400	4.5 to 4.9	17		Thiosorbic lime	New	Jun 1976	400	ESP	UOP		29
	Conesville, Unit No. 6	400	4.5 to 4.9	17		Thiosorbic lime	New	Jan 1978	400	ESP	UOP		29
Indianapolis Power and Light	Petersburg, Unit No. 3	530	3.0 to 3.5			Limestone	New	Apr 1977	530		4 modules; UOP		29

Table 33. FGC WASTE DISPOSAL STATUS

Utility	Power Station	FGC Waste Treatment Processing				FGC Waste Disposal			Ref.
		Processor	Fixation Material	Waste Solids Content	Treatment Conditions	Interim Storage	Transport Mode	Final Disposal Site	
Commonwealth Edison Co.	Will County, Unit No. 1 (167 MW)	Own with Chicago fly ash	Lime and fly ash	35 to 45% clarifier underflow	10% lime and 20% fly ash (of dry sludge solids)	7-acre on-site clay-lined disposal basin (prior to Sep 1975	Rotary mix concrete truck	Offsite to permanent landfill disposal site operated by Material Service Co. since Sep 1975	29-31
Duquesne Light Co.	Phillips (387 MW)	Calcilox®	Calcilox®	30 to 40% clarifier underflow	10% on dry sludge basis	Three curing ponds, 6000 yd³, each with 10 to 14-day capacity	Dump truck	~ 1 mi from plant; 2-yr capacity	22, 32
		IUCS		30 to 40% clarifier underflow	~400 tons processed; material produced in 4 weeks, ~ 70% solids, Jun 1974			Isolated area in landfill operations	22, 25, 29, 33
		U.S.U.S.	Fly ash and bottom ash		Various				33
	Elrama (494 MW) 1st scrubber in service, Nov 1975	IUCS, 10-mo contract starting Sep 1975	Lime and fly ash	35 to 40% clarifier underflow, filtered to 50 to 60% solids before treatment	Treating waste produced by 210 MW equivalent, using equipment from Mohave site tests		Truck, 25-ton capacity	Landfill, ~ 2 mi from plant	22, 33, 39
SCE	Mohave, Unit No. 1	IUCS			Treated all sludge from 167-MW system for 1 yr			Landfill of 25,000 tons for housing; parking lot construction; streets and roads in Bullhead City and Riviera; synthetic aggregate manufacture	25, 29, 35, 36
	Mohave, Unit No. 2	Dravo	Calcilox®					Unlined pond	25
CAPCO Group	Bruce Mansfield, Unit No. 1 (825 MW)	Dravo	Calcilox®	30% solids clarifier underflow		None	Treated waste pumped to disposal site, ~ 7 mi; pond supernate returned for reuse	400-ft high embankment dams a 1350-acre valley	22, 37, 38
Ohio Edison Co. Duquesne Light Co. Cleveland Electric Co. Toledo Edison Co. Pennsylvania Power Co. (operator)	Unit No. 2 (825 MW)							Site estimated to be adequate for 20 to 25 yr	
LG&E	Paddy's Run (65 MW)	LG&E	Carbide lime; fly ash mixed at disposal site	22 to 26% solids in clarifier underflow, filtered to 35 to 45% solids	3 to 5% additive (dry sludge basis) added in thickener		Truck 1 mi at $0.50/ton	10-acre borrow; pit depth, 20 to 30 ft.	40
	Cane Run, Unit No. 4 (178 MW)	LG&E							22, 29
	Mill Creek, Unit No. 3 (425 MW)	LG&E							22, 29
Columbus and Southern Ohio Electric Co.	Conesville, Unit No. 5 (400 MW) Conesville, Unit No. 6	IUCS IUCS	Lime	Thickener underflow at 30% solid. Secondary thickening then vacuum filtered to 50 to 60% solids	Fixation plant to be completed, May 1976. Blend with dry fly ash		Disposal site 1/3 mi from plant; fixation plant midway; conveyor from fixation plant to disposal site	75-acre (minimum) lined landfill, 10 to 20 years at site	25, 39, 41, 42
Indianapolis Power and Light	Petersburg, Unit No. 3 (530 MW)	Dravo	Calcilox®					Landfill	39

SECTION VIII

FOREIGN TECHNOLOGY

8.1 JAPAN[43]

Japanese flue gas desulfurization (FGD) nonregenerable processing experience is the most advanced of foreign technology; significant information is available in Reference 43.

The discarding of calcium sulfite sludge is not as widespread in Japan as it is in the United States because of limitations on land available for disposal. Recently in Japan, about six million tons yearly of SO_2 have been emitted, mainly by the burning of heavy fuel oil. Since many desulfurization plants will be built, it is likely that the supply of by-products will far exceed the demand and that a substantial portion of them will be discarded. Gypsum is generally considered the most reasonable by-product because the demand for it is increasing and because it is considered as an easily discarded material. The various by-products from nonregenerable waste gas desulfurization processes are discussed in the following sections.

8.1.1 Calcium Sulfite

Limited quantities of calcium sulfite FGD wastes have been produced in Japan because of its lack of utility and lack of available land for discarding it. Mitsui Aluminum Company, which has produced a calcium sulfite sludge since 1972, plans to use the gypsum production process for new installations because of the poor properties of the sludge. There is no interest in chemical treatment, as there is in the United States.

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A synthetic paper from fairly pure calcium sulfite and polyethylene, at a weight ratio of about 70:30 has recently been produced. The product has some defects and is now undergoing improvement.

8.1.2 Gypsum

Most of the large sulfur oxide recovery plants now under construction or being planned are oriented toward the production of the by-product gypsum. This approach is being taken for a number of reasons: (1) Japan has large quantities of limestone; (2) the value of other by-products, such as sodium salts, sulfuric acid, and ammonium sulfate, is not expected to increase since they are already in oversupply; (3) production of elemental sulfur from SO_2 in waste gases is complex; (4) Japan has little available land on which to dispose of calcium sulfite sludge; (5) demand for gypsum has been increasing considerably; and (6) gypsum is considered suitable for disposal in case of oversupply. To date, all of the by-product gypsum has been used for wallboard production and as a cement setting retardant. Since 1971, there has been a slight shortage of gypsum in Japan. However, since many gypsum-producing desulfurization plants are to be installed, an oversupply is likely to occur in the future.

For wallboard production, gypsum of an appropriate crystal size (longer than about 30 μm and thicker than 10 μm) and high purity is desired. Gypsum obtained from oil-fired flue gas and from most other gases usually meets these requirements.

The by-product gypsum is nearly white or light brown. Users of gypsum for cement and wallboard have gradually become accustomed to the colored product, resulting from the small amount of dust derived from the oil-fired flue gas as it passes through electrostatic precipitators. The material is reported to have no adverse effect on the gypsum properties.

The thickness of gypsum crystals is generally an important factor in the strength of wallboard. Crystals obtained from wet-limestone processes are not very long but have considerable thickness and are considered ideal for use in wallboard.

For use as a retarder in the setting of cement, gypsum should contain less than about 10 percent moisture because wet gypsum gends to form a "bridge" in the hopper and cannot be charged smoothly to the cement mill. Normally, by-product gypsum contains less than 10 percent moisture after being centrifuged. Well-grown gypsum crystals produced by some of the indirect limestone processes (100 to 500 µm) contain only 5 to 7 percent moisture after being centrifuged. The presence of sodium in gypsum can adversely affect the property of cement, but the amount of sodium in gypsum produced by the sodium-limestone process is negligible because of the ease of washing due to the large crystal size. Ten percent fly ash in gypsum is reported to have no detrimental effects. Calcium sulfite can be used also for a cement setting retardant replacing a portion of the gypsum. Magnesium sulfate and calcium chloride in amounts less than 0.5 percent may have no adverse effects on wallboard and cement production.

Since a considerable oversupply of gypsum may occur in the future, many groups are investigating new uses for it. The most promising new use is as a building material. The usual type of calcium sulfate hemihydrate (β type) has lower strength than concrete (Figure 25). The hemihydrate of α type has a much larger crystal size and higher strength than β type but is fairly expensive. The II-anhydrite, which is obtained by heating gypsum at 950 to 1000°C, hydrates fairly rapidly and increases in strength when a small amount (1 to 2 percent) of potassium sulfate is added. Recent tests have shown that an anhydrite of good quality can be obtained with by-product gypsum from SO_2 recovery if the fly ash content is less than about 5 percent. A larger amount of fly ash tends to decrease the strength.

Technology for reinforcement of gypsum with glass fiber has been developed recently in England.[43] The reinforced gypsum from α type hemihydrate has compression, bending, and tensile strengths equal to and an impact strength higher than asbestos-reinforced concrete.

A well known limitation in the use of gypsum as a building material is its lack of resistance to water. To eliminate this deficiency, a

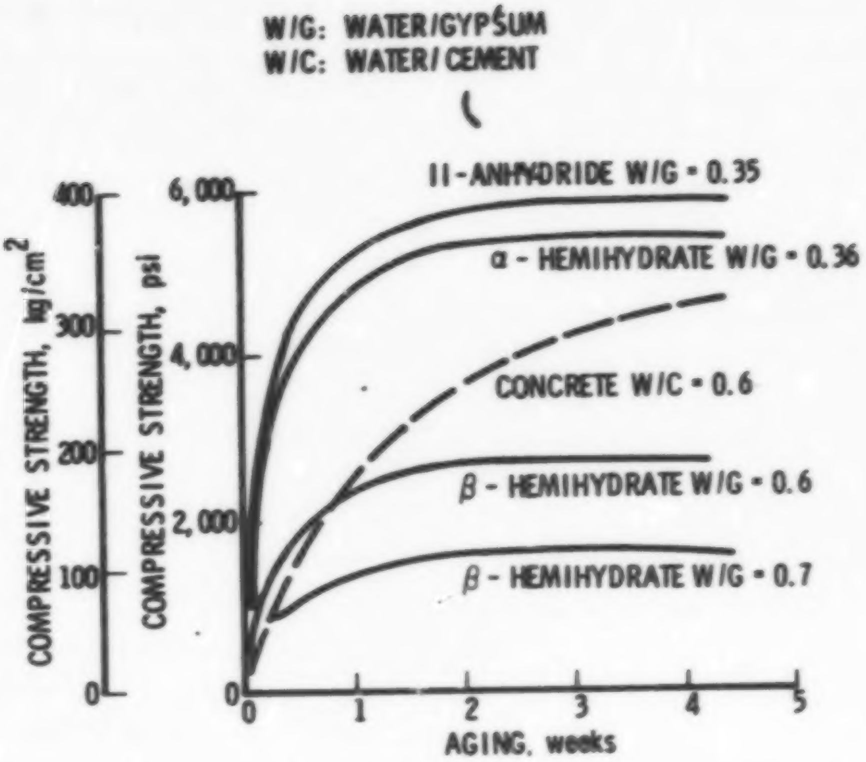

Figure 25. Strength of various types of gypsum and concrete

gypsum plastic composite has been recently developed in Japan. Usually, a resin monomer such as methyl methacrylate or styrene is used for impregnation. The monomer is polymerized by a thermal catalytic process. The composite is reported to have high strength, to be resistant to water, acids, and bases; and to have good workability. It is also semi-incombustible. It may, therefore, have potential as a high-grade building material.

8.2 WEST GERMANY

The Hőlter process includes the oxidation of FGD waste to form by-product gypsum.[44] In describing the operation of over 7000 hours of a 40-MW-equivalent prototype plant, the stack gas with SO_2 content in the range of 600 to 875 ppm SO_2 was scrubbed with a special washing fluid. After additional washing in a venturi, drying, separation, treatment and oxidation, a gypsum with less than 0.5 percent $CaSO_3$ was produced.

The washing solution is reported to be clear and alkaline and does not involve a lime slurry. Rather, the Hőlter process is reported to use a solution of lime innoculated with chlorides and Absorben '75.

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